THE DEVELOPMENT OF AN INTERACTIVE LEARNING ENVIRONMENT BASED ON THE MARKET GROWTH MODEL TO INCREASE THE UNDERSTANDING OF SYSTEM DYNAMICS.

THESIS SUBMITTED IN PARTIAL FULLFILMENT OF THE REQUIREMENTS FOR MPHIL IN SYSTEM DYNAMICS FROM UNIVERSITY OF BERGEN

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NOVEMBER 2020

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Acknowledgement

First and foremost, I would like to express my sincere gratitude to Prof. Pål I. Davidsen, my supervisor, for his unlimited patience while guiding. This work would not have any end without his critical insights and enthusiastic encouragements. I got the opportunity to get fed by his top-level intellect and deep knowledge of the subject area. Thank you very much for believing in me for such a critical topic. My gratitude also extends to other professors and faculty staffs for providing me support and valuable suggestions.

I appreciate the help from my colleagues during the first year never ending assignment sessions both at the campus and outside. The tedious moments would not been turned to the fruitful outputs without those critical discussions and supports we shared those days.

I am always indebted to my brave mom for daring to send me to school as the first girl child at that remote place where most of the girl child are still striving for getting the proper education. Those first steps are the foundation of my journey towards the knowledge achievement. I am thankful to my family for their unconditional love and support throughout the duration of my educational journey.

Thank you very much.

Abstract

This thesis has been focused on the development of Interactive Learning Environment (ILE) for the master´s students of System Dynamics at University of Bergen. Market Growth Model has been used for the purpose. Scaffolding of the Market Growth Model has been done with the help of Stella Architect software. The main purpose of the so developed ILE is to assist the students to enhance their capability of understanding the system dynamics by teaching them the behavioural aspects resulting from modelling and simulation. The modelling was done step wise and the simulated behaviour was discussed accordingly.

The problems associated with the study of System Dynamics modelling are comprehensive, complex and multidisciplinary. The existence of accumulations, feedbacks, delays and non-linearity make these problems difficult to understand.

Structure produces various kinds of behaviours and on the basis of those behaviours, further structural additions and adjustments can be made to achieve the desired pattern of behaviours from the system. In linear systems, the behaviour patterns produced might be simple exponential growth, exponential decay and steady state equilibrium or it might be the combinations of those simple behaviours e.g. S-shaped or goal seeking patterns, S-shaped growth and decay and oscillations. In non-linear systems patterns may be considerably more complex.

Scaffolding has been done by following the assignment sequence of the development of market growth model. The basic market growth part with no market or capacity constraints, the introduction of limited marked, the introduction of the capacity constraints and its utilization and at last the market response to the delivery delay. Moreover, the Open Loop Steady State Gain is use of, the Monthly Profit is being portrayed descriptively as well as utilized normatively i.e. by way of optimization can be completed for the purpose of achieving the maximum profit for the firm where there is a trade-off between a small Sales Force with less effective representatives.

Although there is a potential for the decay in the Sales Force exists, the predominant, basic structure tends to cause reinforced growth. Introducing a limited market shifts that growth to an S-shaped where the growth in Sales Force is balanced by the decay in Sales Effectiveness. The introduction of capacity constraints and utilization part introduces a discrepancy between

incoming and executed orders (i.e. Order Rate vs. Shipment Rate); resulting in a Backlog bubble that is eliminated when capacity is made available as a result of a delayed capacity expansion in response to delivery delays. The result is still S-shaped growth, but the growth rate is less prominent. Finally, there a market response to delivery delay is being introduced in that the market responds less effectively (i.e. with less orders) to the sales representatives when the delivery delay is above normal. The interaction between the internal (company specific) capacity-expanding response to the delivery delay and the external (market-specific) order contracting response to the delivery delay, produces an oscillatory behaviour that is superimposed upon the basic S-shaped growth experienced when no market response had been introduced.

There are a number of reinforcing and balancing loops formed in the course of the modelling process. There is a major loop that acts as a reinforcing loop R1, in the basic market growth sector supplemented by three negative loops regulating, respectively, the Backlog, the Recent Revenue generated and the Sales Force. With the addition of a limited market sector, a major balancing loop, B4, is introduces. With the addition of a capacity constraint and utilization, one local balancing loop B5 and two major balancing loops B8 and B9 are being introduced. The capacity sector also introduced two reinforcing loops - one which includes the basic Sales force and that, in addition, includes the B5 component of the capacity sector and another loop includes the remaining capacity sector. Similarly, there is another balancing loop, BX introduced after the addition of the market response to delivery delays. Reinforcing loops are responsible for the exponential growth and decay whereas balancing loops alter the exponential nature of those reinforcing loops. The nature of the loops is affected by the values of variables involved and that act as parameters characterizing the relative significance (strength) of each loop, i.e. in the course of the dynamic development of production. The resulting variety of behaviour modes is being discussed in the course of the scaffolding process.

One separate ILE has been developed for looking at the growth obtained by the system. Traditionally, the growth concept was developed as Open Loop Steady State Gain (OLSSG) which is calculated by the overall effect of all the parameters involved in the system. When the system is in equilibrium state the OLSSG is 1. When the value of OLSSG exceeds 1 then the system is having overall growth whereas when its value is below 1, the system is having overall decay. There was no calculation of the effect of delays over the growth of the system.

When the system gets to the steady state condition it goes through a transition phase which must be taken into consideration. There must be something which affects the growth directly. If we focus on the delay part for each stock, we can see the delay has an effect on the system to achieve the steady state condition. When there is more delay the system takes much longer time and when there is less delay it takes shorter time to achieve the equilibrium state. That means there is longer transition period when there is more delay and there is shorter transition period when there is less delay. When the system is not in the equilibrium condition there is the difference between input and output. When we take the ratio of output and input, it is always either positive when there is growth or negative when there is decay. So, such ratio plays a significant role to determine the growth of the system. Each of such ratios compensate the total growth of the system along with the OLSSG component. Such ratios together make a component which plays a role to determine such gain and is named as Transient Gain Component, (TGC). In the case of Market Growth Model, we calculate such ratios for Shipment Rate to Order Rate and Recent Revenue to Revenue.

It is expected that the ILE developed will help the students to gain the modelling skills required to develop and analyse models of the complexity characterizing the Market Growth Model. In addition, the ILE developed for calculation of overall growth for the system will give the students a new insight.

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CHAPTER ONE: SYSTEM DYNAMICS LEARNING FACILITATED BY THE INTERACTIVE LEARNING ENVIRONMENT

1.1 Introduction

System Dynamics knowledge, required to engage in modelling and model-based analysis, is typically acquired in two phases. The first phase focuses on the basic structures- the building blocks used in modelling. In the second phase, the focus is on the model building, the resulting behaviour produced by such model, and the relationship between structure (produced model) and behaviour (produced after simulation of such models). In this thesis we aim towards supporting learning in this second phase. We are focusing on the relationship between the structures of the complex, dynamic models that represent non-linear feedback systems, and the dynamics (i.e. behaviour) produced by such models when one subjects them to simulation.

A fundamental principle of system dynamics states that the structure of the system gives rise to its behaviour. (Ross 1977 cited in Sterman, 2001). As Prof. Pål Davidsen describes in his work, dynamic behaviour arises as a consequence of the interaction between variables that represent the attributes of the system modelled (Davidsen, 2000). The structure consists of the feedback loops, stocks and flows, delays and non-linearities and created by the interaction of the physical and institutional structure of the system. The basic modes of behaviour in dynamic systems are identified along with the linear feedback structures generating them. These modes include divergent behaviour, created by positive feedback; convergent behaviour, created by negative feedback; and oscillations (including damped or reinforced oscillations, limit cycles, and chaos) created, predominantly, by negative feedback with time delays. More complex modes such as S-shaped growth (goal seeking) and overshoot and collapse arise from the nonlinear interaction of these basic structures (Sterman, 2000). In this thesis, an attempt has been made to develop the structure of different sectors of the Market Growth Model step by step and side by side, describe and explain the associated behaviour.

1.2 Learning System Dynamics

There are multiple perspectives on learning (S. Fard 1998 shown in J. Michel). System dynamics is mainly based on the notion that structure produces behaviour; thus, learning system dynamics facilitates proper understanding of the structure-behaviour relationship and allows for the purposeful modifications of structure to get the intended behaviour (Davidson and Spector 1997). Technology allows for effective knowledge transfer i.e. graphical portrayal of the model structure, the behaviour produced and the intimate relationship between the two so as to promote learning. Such learning can be accomplished by using a ready-made model by performing a variety of simulations and by analysing the results after such simulations. Alternatively, the model may be built by the learner as a part of this process. The learner may also start with an existing model and expand the model as needed prior to the simulation and analysis (Alessi, 2000).

In this thesis, we will be focussing on Learning with Models i.e. learning system dynamics by the use of an already existing model based on a case study. The learner may, however, be expected to produce that model and to investigate his own version of the model, rather than merely by the way of the ILE deployed. the learning process is based on a modified version of the Market Growth Model (as a case) originally proposed by Jay W. Forrester (Sterman 2000). The learning focuses on a step by step model building process and the subsequent analysis of the relationship between the resulting model structure and its dynamic behaviour and is intended to build the skills required by a modeller.

On the one hand, case studies typically play a significant role in learning system dynamics and on the other hand, in addressing case studies, system dynamics experience may play an important role. In other words, we may facilitate the learning of system dynamics might be facilitated by modelling a problem from the scratch or by utilizing already existing model of that problem. Thus, we need to distinguish between those two approaches as mentioned Learning by Modelling and Learning with Models (Davidsen et all, 1999).

Using a case study for learning System Dynamics takes this process one step further. It expands the system dynamics skills in the process of addressing the case study, -a well-structured representation of a real problem. In particular, the learner develops modelling and analysis skills along the way. In that case, the learner is a model builder that, in addition, learns how to analyse dynamic behaviour in the context of the case study. In subsequent case study, the learner is expected to generalize and apply the principles of model building and analysis so as to practice their skills. The purpose would then be to adapt, apply and extend that knowledge and those skills, - whether they are to be on modelling or while analysing the produced behaviour.

The process that helps to adopt the new knowledge and skills to fulfil the existing knowledge gaps is learning (Hogarth, 1981 mentioned in Sterman, J. D., 2000), and, as portrayed, learning is a feedback process, preparing learners for making our decisions that alter undesirable behaviour to a desirable one by way of structural modification. In reality, we learn by receiving information about the world and revise our decisions in response to that information and our mental understanding of the systems structure. Feedback is the behaviour which affects the output (Sterman, 2000). For learning purposes, we may substitute reality with simulation models that have a structure representing the reality under investigation and that produces a behaviour that replicates the dynamics of that reality.

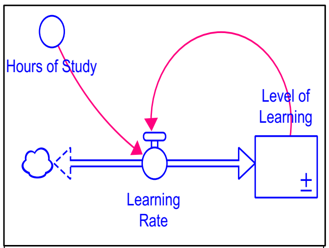


Fig: 1.1 - Most basic type of feedback loop.

The single feedback loop shown in the figure left describes the learning process using basic concepts of System Dynamics. There is a state called stock represented by Previous knowledge Level, and another stock representing the level of learning (knowledge/skill) attained as Acquired Knowledge, - which accumulates the Learning Rate, i.e. the flow of information gained. The information is also influenced by the state itself and the time spent for the study. Such loop might be extended having the desired state shown as Target Level to Acquire Knowledge. In such case, there must be some action taken to fulfil that gap which causes the actual world to move towards the desired world.

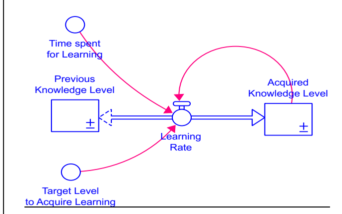


Figure 1.2 - Feedback loop with some desired state to be achieved.

This study addresses the creation of a learning environment to support for students when learning about the relationship between model structure and model behaviour. Stock and flows (delays) and nonlinear relationships are the building blocks of complex dynamic behaviours in systems (Ng, Sy & Chye, 2012). System Dynamics is considered as a methodology that bridges the gap between our understanding of structure and behaviour of complex dynamic systems. The structural description captures the static aspect of the system and the behavioural description represents its dynamic aspect. Purposeful modification of structure can be made with an intent to produce a desired behaviour in the system. Graphical integration enhances our understanding of the most generic process that links structure to behaviour in dynamic systems (Davidsen, 1991).

1.2.1 Structural Learning

Structural learning includes learning about the building blocks and their assimilations in the model structure. Building blocks also known as basic structures, -stocks, flows and variables (converters) and their assimilated structures are causal loop diagrams (CLDs) and stock and flow diagrams (SFDs).

A. Causal Loop Diagram

Causal loop diagrams (CLDs) are flexible and useful tools for diagramming the feedback structure of systems in any domain. While, model boundary charts and subsystem diagrams show the boundary and architecture of the model, CLD shows the cause and effect relationship between the variable that form a system (Sterman, 1994). In general, CLDs exhibit, in a simplified way, how the variables are related within the system.

B. Stock and Flow Diagram

The stock and flow diagrams (SFD) elaborate the description of the feedback structure of a system. It provides a more accurate representation of the nature of the relationships that constitute the systems structure. In particular, SFD describes the accumulation processes that govern the progression from one state to the next over time, and thus the time-consuming processes governing the systems behaviour.

1.2.2 Behaviour as a point of departure for Learning

Behaviour-based learning is learning about the various modes of behaviours produced by different system structures. Behaviour can be considered and analysed in isolation, variable by variable. But from a systems perspective, the behaviour of individual variables is generated by the structure that relates the variable under investigations to other variables. In this thesis the emphasis is on behaviour. Using that as a point of departure, the issue at hand is what structural components that produces the observed behaviour. This is why the Interactive Learning Environment developed combines seamlessly structure and behaviour. Along with the behaviour produced is a diagram of the underlying structure so as to expose its origin and allow for an analysis of the relationship between structure and behaviour, -how the underlying structure produces behaviour and how the behaviour feeds back to modify the relative significance of the underlying structure components. It has been an educational challenge to establish an understanding of the relationship between structure and behaviour in complex systems (Davidsen, 1991). Graphical integration is an example of a skill typically acquired early on by system dynamicists. It enables the learner to enhance their understanding one of the most generic processes that links structure to behaviour, the accumulation (integration) process (Davidsen, 1991) that takes place in the transition from flow rates to stock levels.

1.3 The Problem Statement

With complex systems as a thematic research domain, we address an important class of problems in our society that all share of the characteristics outlined as follows:

1. *The problems are associated with dynamic systems, i.e. they develop over time, governed by an underlying systems structure (Sterman 2000).*

2. *The problems are comprehensive in the sense that they cut across sectors, private as well as public, and are multi-disciplinary in nature (Ng, Sy &Chye, 2012))*

   Such problems are often not recognized comprehensively or being recognized to the extent that they are not well-defined. Thus, it becomes challenging even to communicate effectively about such problems. Moreover, there is very limited access to competencies in methods, techniques, and tools developed to effectively identify and solve such problems and, finally, the knowledge transfer is inhibited.

3. *The problems are characterized by underlying causal structures of accumulation processes that are interrelated by the way of non-linear feedback structures. The variety of lags / delays makes the root cause of the problem/s more complex to access. In addition, feedback system in the complex systems leads to circular arguments; make the system meaningful only with the recognition of associated lags / delays (Sterman, 2000).*

   In non-linear systems, feedback loops synergize to impact the systems' dynamics and the impact of each systems component changes over time. Successful interventions in such systems are typically aimed at reinforcing the significance of favourable components and reducing the significance of less favourable ones. We may only accomplish that with the understanding that favourable structures often turn unfavourable as a consequence of the dynamics of the system itself, i.e. from within (Sterman, 2000).

4. *Time horizon defines the problem as well as its solution and extensive time horizons imply more feedback and non-linearity. Moreover, an extended time horizon widens the operating interval and activates dormant non-linear relationships in the systems structure (Sterman, 2000).*

In essence, the problems are comprehensive, complex and multidisciplinary. Accumulations, Feedbacks, Delays and non-linearity make them difficult to understand. To that end, one needs a fundamental understanding of the structural and behavioural origin and nature of the problem. System dynamics modelling and model-based analysis has been designed for that very purpose. Consequently, in learning system dynamics the search for structural, causal explanations of dynamic behaviour is essential in order to understand the relationship between structure and dynamics in complex systems and in order to modify structure in a way that effectively and sustainably improves the resulting dynamics (Davidsen, 2000).

In the research behind this the intention is to expose the students to a problem that holds all these characteristics: there are four time-consuming accumulation processes and a number of feedback loops in play. Moreover, in the production of orders there is a non-linear interaction between the Sales Force and the Sales Effectiveness, -in part affected by the size of the Sales Force and in part by the market response to delivery delays. Finally, there is a non-linear limitation of the Shipping Rate, determined by the capacity to ship (i.e. to produce).

1.4 System Dynamics Related Learning Challenges

It has been an educational challenge to establish an understanding of the relationship between structure and behaviour in complex systems (Davidsen, 1991). According to Sterman, learning about dynamic systems is difficult and rare because a variety of structural barriers hinder the feedback processes required for learning to occur. As he mentioned, there are a number of barriers to learning SD as ´dynamic complexity, limited information, confounding variables and ambiguity, bounded rationality and the misperceptions of feedback, flawed cognitive maps, erroneous inferences about dynamics and judgmental errors and biases or unscientific reasoning make learning complex systems complicated´ (Sterman, 2000). It is that we, with an effective learning environment, may lower or even remove some of these barriers, -including the time it takes to provide feedback. The introduction of the ´Live´ mode functionality offered by Stella Architect, offers an unprecedented opportunity to provide instant feedback.

The learners are expected to understand the relationship between the model structure and the resulting dynamics unfolding over time. I.e. with reference to the underlying model structure, they are expected to be able to explain the dynamics exhibited by the model in the form of the simulation results. Complications arise due to the difficulties in understanding accumulation, feedback, delays, and non-linearities which are the main causes for challenges facing learners of complex dynamic systems. They all go side-by-side and synergize in causing learning challenges. Accumulations are caused by the flow/stock structures and are consuming time (constitute delays) and they are present in feedback loops that are typically interrelated non-linearly. Since these elements of system structure xo-exist and are interrelated, they synergize in producing the complex behaviour that we analyze and consequently they must be addressed in the context of each other, - not one-by-one (Sterman, 2000). For simplicity, however, these concepts are first discussed individually before they are being addressed altogether in the description of the case study at hand. Figure 1.3 below is relevant as a foundation for the discussion of all the concepts addressed.

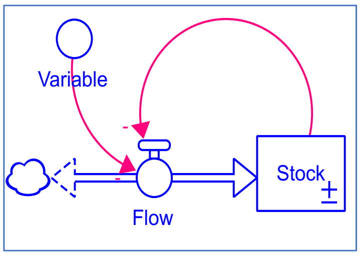


Figure 1.3 -A basic Feedback loop

In summary, learning complex dynamic system possesses the following challenges:

1.4.1 Accumulation and delays

To understand dynamics of the complex systems, the learners must fully comprehend the accumulation processes that time span, - i.e. the integration of flow rates into stock levels. This is because the integration process transforms the dynamics of a flow rate into the dynamics of the associated stock level (Sterman, 2000). One of the hardest, basic lessons to learn is that accumulation processes take place over time and that they, consequently, imply delays or lags. The implication is that an instantaneous change in a flow rate has no immediate effect on the associated stock level. Any effect it may have unfolds over time and may only be observed as time passes by (Sterman, 2000).

Dynamic change arises only from the accumulation or decumulation taking place in each stock over time i.e. from a change in the state of the system. The pattern of the rates of the inflow to and the outflow from the stocks determine the patterns of the stock levels over time. The common practice of considering differentiation and integration as the inverse of one another tends to obscure the direction of causality (Davidsen,1991). Understanding accumulation (i.e. integration) is claimed to be the most common difficulty on understanding the behaviour of complex systems (Moxnes, 2004). In fact, it should be vastly more intuitive than the reverse, - the differentiation, - where the question is not what change in a stock level does a flow rate cause, but what flow rate has caused the change in a stock level. Forrester puts it this way: ``One can go a step further in questioning the differential equation description of a system and call attention to the fact that nowhere in nature does the process of differentiation take place. In teaching system dynamics, we have found it much easier and much more natural to the student to deal exclusively with the processes of integration and to make no reference to differentiation. Differentiation is seen as a mathematical artificiality which does not have a real-life counterpart in the systems being represented`` (Forrester, 1968).

Stocks in system dynamics mainly represent net accumulation of the associated flows over time. Stocks are the accumulations (Sterman, 2000) and governed by the following equation-

$$\text{Stock}(t) = \text{Stock}(t - dt) + (\text{NetFlow}) \times dt$$

Such accumulation is not instantaneous and implies delays because the stock and flow relationships as described in the stock equations spans time. The problems arise from complex systems, characterized by an underlying causal structure of accumulation processes, the core of any dynamic system. They are ubiquitous, i.e. present in every feedback structure that cut across sectors and disciplines. Hence, understanding accumulation processes taking place in a system is essential task in overcoming System Dynamics learning difficulties. The stock equation is a clear expression of the feedback into the stock itself, -a feedback that is not represented in regular feedback loop diagrams. If they had been so, then the stocks could be identified in such diagrams.

One may understand accumulation processes structurally from the stock equation, but, since time is so predominant, the behavioural implications of accumulation processes may best be understood by observing real life phenomena or by way of simulation. Hence simulation based interactive learning environment may play an important role in establishing such an understanding.

Delays cause the effect of a change in a systems state to dissipate through a system over time, - typically also in space. Delays between the time a decision is being taken and its effects on the state of the system are common causes of problematic behaviour. Instabilities arise in the premature expectation of a systems response. Thus, when the system is perceived not to respond in time, the lack of response is mis-interpreted and a new (often reinforced or reversed) decision is being make, eventually causing overshoots and/ or oscillations. Oscillation and instability reduce the understanding of the complex system (Sterman, 2000).

In reality, such delays reduce the velocity of the learning loops, so as to disturb the ability to accumulate experience, test hypotheses and make improvements. Consequently, delays tend to hamper learning. One way to circumvent learning in reality is to employ interactive learning environments, in which time may be compressed so as to facilitate instant feedback and improve the learning process.

1.4.2 Feedback

A feedback structure is one that causes the change in the state of the system (i.e. in the stock levels characterizing the system at any point in time) to be determined by the current state of the system. It constitutes a closed circle involving a sequence of variables (Sterman, 2000). The state of a system is often influenced by itself through a variety of feedback loops and that, in non-linear systems, interact. This implies that the effect of a stock level on a change in that stock level, may be conditioned by the levels of the remaining stocks in the system. The implication is that the strength of that feedback loop may be modulated by changes in the values of the state variables (stock) in the system (Davidson, 1991). Feedback loops lead us into circular arguments that includes lags/delays. In Circular reasoning, a cause may be considered an effect and an effect a cause, if one does not recognize the accumulation processes included in every feedback process, -the ones that extends the feedback circle into a spiral that is spanned across time.

Feedback loops are characterized by their polarity. Traditionally, feedback loops have been characterized as positive and negative. Note, however, that, contrary to the impression left by static feedback loop diagrams, loop polarity may change in the course of time. Feedback loops of positive polarity cause a self-reinforcing development over time whereas of negative polarity cause a self-correcting (reactive) development over time. The dynamics of the complex systems arise as a result of the formation of networks produced by the interaction of these feedback loops (Sterman, 2000). In order to understand a systems behaviour, therefore, we must identify the root cause of shifts in polarity as well as in feedback loop dominance (strength) and trace those properties across time. Simulation based interactive learning environments are well suited for such tracing.

The problems are concerned with the dynamic systems and developed over time. The feedback leads us into circular arguments considering lags/delays in the system. In non-linear systems, feedback loops synergize to impact the dynamics of the system. This feedback mechanism helps us to identify the underlying problems and their corresponding remedies. In non-linear systems the impact of each systems component changes over time; hence, governing sub-structure must be identified at any point in time to facilitate an effective learning. The information system and its characteristics can change as we learn on the basis of the feedback we receive. Changes in our mental models are constrained by what we previously chose to define, measure, and attend to i.e. ´Seeing is believing and believing is seeing´ (Sterman, 2000).

1.4.3 Non-linearity

Since the gains are typically formed by the parameters multiplied at various locations along a feedback loop, the effect that one feedback loop has on some other loop is multiplicative and thus a result of a non-linearity. The implication is, moreover, that the state of one feedback loop, may affect the gain in some other loop and that the state of this, second loop, feeds back to influence the gain in the first one. That way the dynamics created by one loop, determines the gain in some other loop, and thus its dynamics, - which feeds back to change the dynamics of the original loop. Such endogenous interactions, often among a variety of loops, is what causes the shifting dynamic patterns of behaviour that, in reality, are exhibited by non-linear, feedback systems. Consequently, the ultimate challenge for learners is to understand how the dynamics created by a non-linear feedback structure in a system is fed back to change the relative significance of the various structural components of the system so as to, in turn; modify the dynamics of the system. This understanding is a key to the management of complex, dynamic systems (Sterman, 2000).

From the beginning, System Dynamics emphasized the multi loop, multistate, non-linear character of the feedback systems in which we live (Forrester, 1961). The pattern of behaviour changes in each time step and hence the non-linearity occurs in the system. In non-linear systems, feedback loops synergize in governing the dynamics of the system. Loop polarity and the impact (strength) of each loop varies over time. This is what gives rise to the complex behaviour of non-linear feedback systems. Hence, the governing sub-structure must be re-identified at any point in time so as to facilitate an effective understanding of the mechanisms underlying an observed behaviour, a true challenge to learning (Davidson, 1991).

This part is developed on the basis of some articles and the in-depth discussion with Prof. Pål I. Davidsen. This thesis documents the design and development of an interactive learning environment aimed at facilitating learning in and about non-linear, dynamic feedback systems. This facilitation takes place through a careful scaffolding process whereby the learners are exposed to models of simple accumulation processes, incorporated in individual feedback structures, interrelated by singular non-linearities. This process allows for the subsequent incorporation of additional accumulation processes, feedback loops, and non-linearities in our models so as to, eventually, match the complexity of real systems (Davidsen, 2000).

The learners in this case are students in the course GEO-SD 303 (Model-based Analysis and Policy Design) who have completed the course GEO-SD 302 (Fundamentals of Dynamic Social Systems) offered by the System Dynamics Group, Department of Geography, University of Bergen. These students are familiar with the basics of modelling, simulation and analysis as pertaining to simple systems structures. In GEO-SD 303, the students are exposed to dynamic reference behaviour, re-challenged to develop a model that replicates and explains the observed behaviour and to identify policies that modifies that behaviour (typically considered undesirable) so as to obtain an improvement (i.e. more desirable dynamics). The students are presented with a description of the system producing the dynamics and are expected to reproduce the systems structure by the way of a system dynamics model, subject the model to simulation, and analyse the resulting dynamics in view of the underlying mode structure.

1.5 *Purpose and Nature*

The purpose of this study is to flip the classroom from teacher-oriented to learner-driven. The teacher becomes a director or facilitator, - one that provides the learning environment, scaffolds when needed, and inspires the learning process. Instead of receiving the knowledge provided through the traditional teaching process, learner would be an active producer and reproducer of the knowledge, by the way of methods, techniques and tools made available by the facilitator through an interactive learning environment (ILE).

Since the modelling is conducted using the graduated complexity approach and the learner is receiving instant feedback after each step, the learner becomes motivated by experiencing the benefit of working with this ILE. It does not only allow the learner to act, but also to react. When the learner changes the assumptions represented in a model, a simulation immediately produces the dynamic consequences of such a change and calls for (i.e. challenges) the learner to explain the resulting dynamics based on an analysis of the underlying model. Thus, a very strong cognitive link is being established between structural cause and the dynamic effects. The learner is also made aware of how using the existing model, structural modification may be introduced to produce more favourable dynamics over time (Spector and Davidsen, 1997)

1.6 *The Interactive Learning Environment*

A variety of methods, techniques and tools have been developed to facilitate learning in and about complex, dynamic system (Spector & Anderson, 2000), among which System Dynamics is one. Since the mid 1990s, System Dynamics based Interactive Learning Environment (SDILE) have emerged as a popular tool for this purpose, - and with it, a number of techniques have also been developed. Depending on the learning goal, such learning environments can be developed for the purpose of analysing a pre-prepared model or with the intent that the learning should develop his/her own model, -or both (Davidsen, 2000).

Supportive Learning Environments are helpful when teaching about complex systems. In the context of system dynamics modelling learning, such learning environments can be created as an extension of the modelling process itself (Maier & Größler, 2000). Students are building and using simulations in both guided discovery and expository learning environments (Alessi, 2000). System dynamics is being used to improve understanding of complex, dynamic systems (Davidsen, 1996; Forrester, 1985; Sterman, 1994). Learners can learn about complex systems either by going through the well-structured model or by modelling stepwise on a case-by-case basis. While modelling, learners engage in understanding of the complex phenomena under investigation and the connection between and among the parts of the modelling. This general commitment allows for both learning with models and learning by modelling (Jackson et al., 2000 in Spector, 2000).

This work is based on the assumption that the system dynamics can be used to facilitate our understanding of dynamic systems (Davidson at all. 1999). An existing model has been used by which the learner can start with model building, simulation as well as a step by step analysis. To facilitate this process, the student-centred Interactive Learning Environment (ILE) has been developed for the learner to learn the complex System Dynamics Modelling process (Biggs and Tang (2011) by using the very same modelling tool, Stella Architect that the learner will be trained in. The main focus has been given to the learner, i.e. learner-cantered and learner-driven learning. Students are supposed to go through the ILE and be guided through all the steps as presented. The facilitation process is written in the form of the STELLA Architecture Interface facility. The intent is to alleviate the teacher or the facilitator in the learning process to prevent their interference and to offer the learners ample room for experimentation, critical thinking and learning. If there is the need for a facilitator, they might appear but that need should become less and less with the time and the support may finally be completely withdrawn. In fact, the ideal ILE should offer the required support in the form of scaffolding with a corresponding withdrawal of scaffolds as the learning process progresses. The decreasing scaffolding is combined with the principle of Graduated Complexity. The complexity of the problem offered starts from the very lower level and increases by the steps presented in the ILE. The intent is to provide a very open-ended environment for learning based on experimentation and exploration with minimal intervention on the part of the teacher or facilitator (Spector and Davidson, 1997).

An ILE that consisting of two components, the underlying model and interface, is created to engage the learner, belonging to a certain audience, in the active and constructive processes that facilitates purposeful learning in and about the complex systems (Spector, 2000). The creation of such an ILE to facilitate learning is based on the principles of graduated complexity and scaffolding.

1.6.1 Graduated complexity

Developing an Interactive Learning Environment for complex dynamic domains is a challenging task (Sterman, 1994, reflected in J.M. Spector). Spector talks about the way we can create learning environment by promoting active and constructive processes in the learner which is a vital part of learning support and instructional design, most especially with regard to advanced learning about complex domains. In a complex system learning process, the knowledge is provided through a very open ended and exploratory or experimental environment with minimal direct feedback or guidance from a teacher or tutor (Spector and Davidsen, 1997). Learning in such complex domains typically starts with a simplified problem definition and thus a simple systems structure, -one that gradually increases in complexity as the learner learns through model building, analysis and reflection. Thus, learners are confronted with increasingly complex aspects of a problem (Spector & Davidson, 1997). Such a process introducing complexity in during the learning process is called graduated complexity. The introduction of graduated complexity is consistent with such current mainstream educational research as cognitive apprenticeship (Collins, 1991) and cognitive flexibility theory (Spiro, Feltovich, Jacobson and Coulson, 1992).

In each step of the way towards increased complexity, the learner may require support, first significant support, subsequently less and less support until the learner is able to solve the tasks facing entirely on his/her own. For this purpose, we imply the educational scaffolding technique.

1.6.2 Scaffolding as the Tool for Creating ILEs

Scaffolding is an educational technique employed to support learners in the beginning of their learning process in order for them to successfully solve the problems and to gain the skills. Using this technique, learners should, gradually, be able to solve problems independently (Collins, Brown, & Newman, 1989; Wood et al., 1976 cited in Belland, 2017). Such support must be well-planned and well-structured. The support is gradually removed and finally the learner is expected to address the challenges that they face on their own.

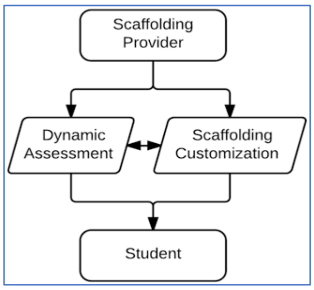


Figure 2.6: Scaffolding Concept

The learning process might consist of many steps with various task to accomplish, often with increasing complexity. The support is continued, increased or reduced based on an assessment of the learner´s progress time by time. The process contains the segregation of the task into many simpler steps so as to highlight the complexity of the targeted task (Belland, 2017). The ultimate goal of scaffolding is that the learner not only gains the skills required to perform the target task independently, but also assumes responsibility for the task (Belland, 2014; Wood et al., 1976). In other words, scaffolding aims at promoting not only the capacity but also the willingness to perform complex tasks independently (Belland, Kim, et al., 2013).

To make the scaffolding process simple and the results interpretable, the model has been divided into several parts. The learning process across and within each part has been scaffolded. The students are encouraged to simulate each step and then describe and explain the behaviour produced after each simulation. Behaviour graphs are then presented to the students for them to validate their understanding of the relationship between the structure and behaviour (Larkin, 2002). The process of scaffolding is made as simple as possible so that the students benefit from every level of understanding that they reach. The latest version of the interface of Stella Architect has been used to scaffold the Market Growth Model in the development of this ILE.

1.7 Conclusion

This thesis is about the building of interactive learning environment by the use of scaffolding and defined as computer-based support that helps students engage in and gain skill at tasks that they are supposed to accomplish to gain the desired skill levels required to understand the complex systems (Belland, 2014; Hannafin, Land, & Oliver, 1999; Quintana et al., 2004), their produced behaviour after simulation and the relationship between both- structure and behaviour. All the students for that particular course will have the access to the learning environment all the time. They will go through every sector of the model and engage in completing the tasks allocated to them.

This chapter reflects the concept of System Dynamics learning in general. The problem associated to learning System Dynamics and the challenges learners facing such as accumulation, feedback, delays and non-linearity have been briefly reviewed. The concept of Interactive learning environment as the tool for learning System Dynamics is presented with the two main principles for the study, -graduated complexity and scaffolding.

This research focuses on the development of a computer based Interactive Learning Environment on the Market Growth Model by using the Stella Architect. The interactive learning environment in this thesis has been developed to guide the modelling process, direct the simulation, facilitate the analysis and allow for a comparison with the expected outcomes. This way, the teacher steps in the background and the student in the foreground. The debriefing concludes with a summary of the specific relationship between structure and dynamics identified in the case study, a distillation of the key insights gained in the form of a generic structure and a generalization of the conclusions reached as a set-up for the subsequent case study.

1.8 Framework

This research and development conducted is comprised of five stages, documented in each of the subsequent chapters. The first chapter is the introductory part. It consists of the background of the study, problem articulation, challenges faced while learning System Dynamics, purpose of the study, interactive learning environment and the graduated complexity and scaffolding as the main guiding principles for creating interactive learning environments. The second chapter explains the Market Growth Model with its Structural and behavioural components in detail. In chapter three, the scaffolding of the Market Growth Model in the form of the Interactive Learning Environment is presented. In chapter four, the concept of total growth of the system has been taken considered where not only the Open Loop Steady State Gain but also the Transient Gain Component is taken as the main factor responsible for the total gain in the transitional conditions. In chapter five, a conclusion is being drawn and recommendations are being proposed.

CHAPTER TWO: THE MARKET GROWTH MODEL

2.1 Introduction

The Market Growth Model was developed to incorporate most of the behavioural patterns produced by the common business entities to understand the complexities of a dynamic model including exponential growth, overshoot, oscillation and stabilization (equilibrium). Forrester´s market growth model represents a single firm competing in an unlimited market. The model reflects the common problems that arise in the interaction between a start-up company and its market. The dynamic that unfold is primarily caused by the capacity constraints characterizing the company, the policy governing capacity adjustments and the mismatch between the reaction of the company and the market to delivery delays resulting from such capacity constraints. All in all, this results in an unstable (oscillatory) growth mode that originates from shifts in the burden of aligning demand with supply, -between the company, adjusting the supply and its market, adjusting the demand. In the case presented by Forrester, a modification of the capacity adjustment policy is suggested as a solution to the problem experienced by the company. The model used in this interactive learning environment is a slight modification of Forrester´s original model whereby a limited marked is introduced so as to impose a mechanism that limits growth (i.e. caused by market saturation). The model consists of a kernel component and three additional components supplemented in the course of the learning process. The kernel component of the model consists of three main sectors: an order fulfilment sector, a revenue generation sector and a workforce management sector. The additional components of the model are market saturation component, the capacity component and the market component. To keep the model as simple as possible, Forrester deliberately omitted many organizational functions and structures. For example, there is no separate financial sector and there is no explicit representation of the competitors which would commonly be essential components in a model of market growth at large (Sterman 2000).

2.2 The Kernel component of the Market Growth Model

The kernel component of the Market Growth model sector represents the firm itself, each sector representing an organizational subunit such as the one responsible for workforce management that leads to order generation, the one responsible for order fulfilment, the one responsible for revenue generation and resource allocation to facilitate workforce management.

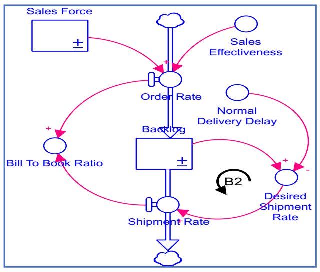


Figure 2.1: Order fulfilment

The Order Rate depends on the number of sales representatives and their Sales Effectiveness as measured by orders booked per sales representative per month. The Sales Force is the number of salespersons recruited for the sales task and Sales Effectiveness depends on the number of sales each salesperson can make per month.

Forrester assumed the firm manufactured a complex high-tech product and operated a build-to-order system. Orders accumulated in a Backlog until they could be produced and shipped. The bill-to-book ratio shows the condition balance between demand and supply, i.e. the balance between the company and the market. A bill-to-book ratios less than one indicates the order book is growing while as a ratio larger than one indicate a decreasing order book. The Desired Shipment Rate depends on the Backlog and the Normal Delivery Time required to process the order, possibly including order processing, construction, packaging and shipping the Order.

When orders are fulfilled, the corresponding products are being shipped. In the revenue generation component of the model, the price per order is fixed. Consequently, the total Revenue generation is proportional to the total number of products shipped. The Revenue is smoothed as Recent Revenue and 20 percent of thus generated Revenue is allocated to the Sales Force management, i.e. the Fraction Revenue to Sales is 0.2.

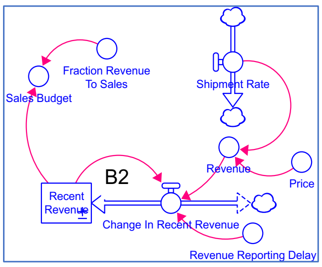


Figure 2.2: Revenue Generation

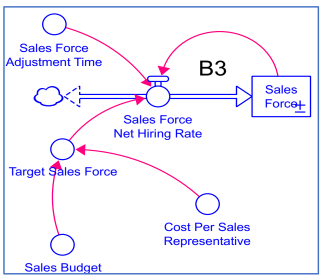


Figure 2.3: Sales Force Management

The number of sales representatives that will constitute the Sales Force adjust to a Target Sales Force that is determined by the Sales Budget, spread evenly across the Target Sales Force, given an average Cost per Sales Representative. The Targeted Sales Force is the main foundation for adjusting (hiring or firing) members of the Sales Force over a Sales Force Adjustment Time. This kernel component of the model thus constitutes the relationships (causal links) between the Order Rate, Backlog, Shipment Rate, Revenue, Sales Budget and Sales Force and forms a major reinforcing loop R1 (fig: 2.4).

2.3 Open Loop Steady State Gain (OLSSG)

In this context, we utilize the Open Loop Steady State Gain (OLSSG) of the model to characterize the steady state condition. The OLSSG is the multiplier that relates the response of the Target Sales Force (effect) back to a unit change in the Sales Force (cause) (Sterman, 2000). So, the OLSSG represents the change in the output (Target Sales Force) that results from a unit change in the input (Sales Force). If OLSSG=1, then the Target Sales Force = Sales Force and the system remains in equilibrium. If OLSSG >1, say 1.01, then the Target Sales Force= 1.01* Sales Force > Sales Force and the system is set up for exponential growth (divergence). If OLSSG <1, say 0.95, then the Target Sales Force= 0.95* Sales Force< Sales Force and the system is set up for exponential decay (convergence). So, the OLSSG determines whether the system will grow (divergently) or decay (convergently). OLSSG in the Market Growth model is defined as the multiple of four factors;

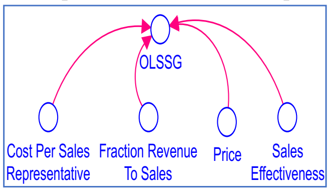


Figure 2.4: OLSSG

OLSSG

=

Sales Effectiveness* Price*Fraction Revenue to Sales*(1/Cost per Sales Representative)

The OLSSG determines the maximum growth or decay of the system. The actual rate of growth or decays is not only determined by the OLSSG but also by the delays characterizing the three balancing loops in the system i.e. the Normal Delivery Delay, the Revenue Reporting Delay and the Sales Force Acquisition Time.

Note that the factor Sales Effectiveness in the OLSSG, is a variable, not a parameter (i.e. a constant). Consequently, the OLSSG varies dynamically. Such a variation will cause an endogenous change in the mode of behaviour of the system, -transitions from say growth via equilibrium to decay.

The gain concept is thus a characterization of the strengths (influences) of the loops that produce the systems behaviour. For a more extensive discussion of the gain perspective on the dynamics of systems, see chapter 4.

2.4 A Market Limitation

The kernel component of the model has been developed on the assumption of unlimited market access which is not possible in reality. In fact, Sales Effectiveness is not an exogenous variable. Consequently, the kernel component was supplemented with a market saturation component. The more sales representatives there are in the Sales Force, the less effective they are. That way, in terms of the Order Rate, an increase in the Sales Force may, on the margin, be compensated by a decrease in the Sales Effectiveness. So, as the Sales Force grows in concert with the Order Rate, Shipment Rate, Revenue and Sales Budget it produces, the consequent reduction in the Sales Effectiveness may lead to a stagnation of the growth in the Order Rate, Revenues and Sales Budget, - and thus the Sales Force Growth may come to a halt. In order to incorporate such a market response in the model, the Reference Sales Effectiveness, Reference Sales Potential, and Market Sales Potential have been introduced as determinants of the Sales Effectiveness. We assume the Market Sales Potential is constant. In an empirical context it may be estimated by way of the reaction of the Sales Effectiveness to a growth (or decay) in the Sales Force.

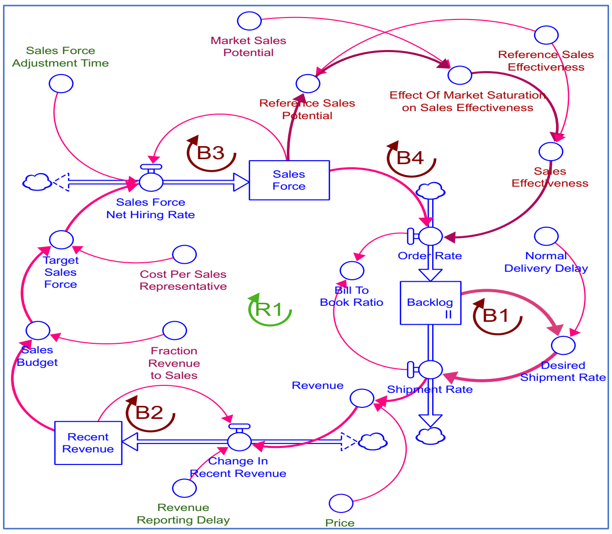


Figure 2.5: Market Growth Model including Market Sector

The Reference Sales Effectiveness and Sales Force combined yield the Reference Sales Potential. The ratio of Reference Sales Potential and Market Sales Potential is an expression of the Market Saturation taking place. The market saturation then, with the Reference Sales Effectiveness, finally determines the actual Sales Effectiveness in the context of limited market.

2.5 *Profit and its Optimization*

Having set the stage for the system to equilibrate, caused by balance between the Sales Force and the Sales Effectiveness of the individual sales representatives, it is time to realize that the fraction of the Revenue that is set aside to finance the Sales Force (Fraction Of Revenue To Sales) affects the equilibrium attained (and the growth towards that equilibrium). In the context of the core Market Growth Model, there is no way to distinguish between the utilities of the various equilibrium conditions. Consequently, the core of the Market Growth Model, equipped with the endogenous reaction of the Sales Effectiveness to the magnitude of the Sales Force may be extended so as to incorporate the costs associated with the sales operation along with the revenues, both already represented in the core model into a representation of the profit, - that may be considered as an utility that may be subject to an optimization (figure 2.6).

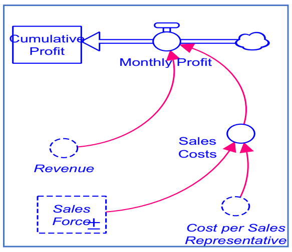


Figure 2.6: Profit

Having identified the Optimal Sales Force with respect to the Monthly Profit, by way of a mathematical analysis, the optimal solution may be applied to initialize the Sales Force, the Backlog, the Recent Revenue as well as the parameter Fraction of Revenue To Sales endogenously.

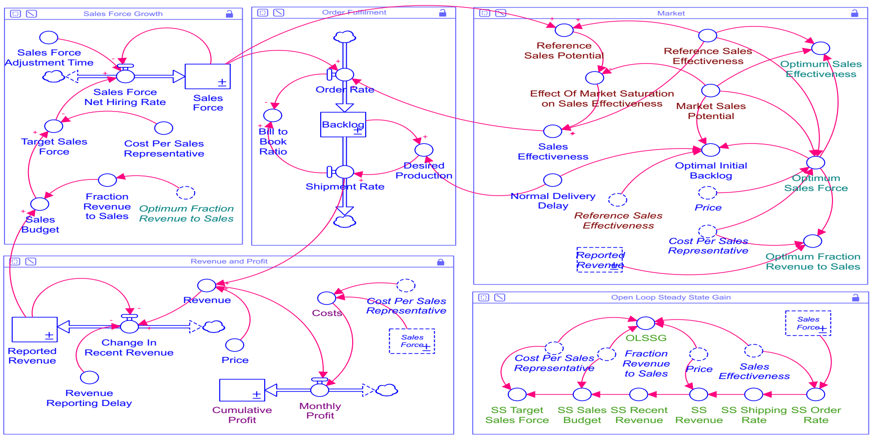


Figure 2.7: SFD including Profit, OLSSG and Optimization

The market sector presented in figure 2.7 captures the optimization of the model in which profit could be achieved at its maximum level. Similarly, model is extended further to capture profitability and Open Loop Steady State Gain of the firm. The figure above shows all the sectors with their variables and parameters of the model.

2.6 Capacity, Capacity Utilization and the Market Response to Delivery Delay

The model so far represents the basic market mechanisms operating under a limited market. Even though the company is assumed to have sufficient shipment capacity according to the situation, it takes time to fulfil its demand and there might be other factors which halt the production capacity to some extent. Consequently, there is the Normal Delivery Delay. Nevertheless, a capacity sector has been introduced in the model. The current shipment capacity determines to what extent the Shipment Rate matches the Order Rate, i.e. the dynamics of the Backlog. How much capacity that the company should acquire and how much of that capacity that should be utilized are both determined by the orders generated by the Sales Force. An indication of the capacity adequacy is the Delivery Delay Perceived By Company. Current Capacity, Capacity Utilization and Shipment Rate are interrelated and influencing each other in the system.

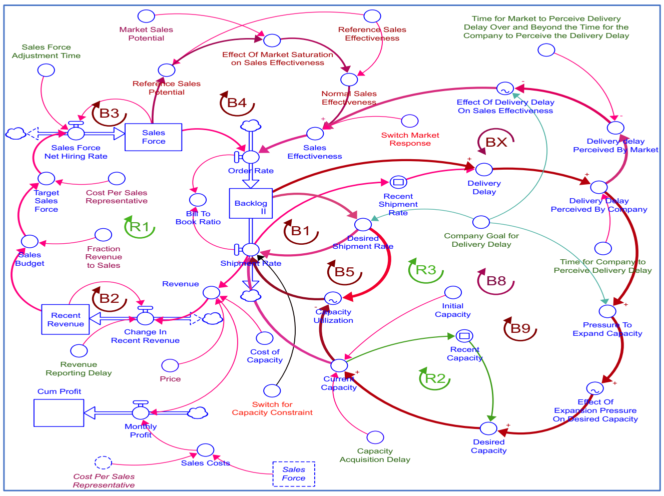


Figure 2.8: Capacity Utilization and its Impact on Market

For the capacity and Capacity Utilization component, the focus is only on the Shipment Capacity. Such capacity is acquired with a significant Capacity Acquisition Delay in response to a Pressure To Expand Capacity resulting from the Delivery Delay Perceived By Company, compared to the Company Goal for Delivery Delay. If the Desired Shipment Rate is below the Shipment Capacity that capacity is utilized to the extent required. If above the capacity, is over-utilized to a certain extent.

The Market Response component represents the market response on the Delivery Delay as perceived by the market. An increase in the Delivery Delay Perceived by the Market yields less to a sales effort. Consequently, the Sales Effectiveness per sales representative is being reduced so as to cause a lower Order Rate.

These two additional model components, incorporating the perceived delivery delay, has a balancing effect on Shipment Rate and the Order Rate, respectively. Three balancing loops B5, B8 and B9 are formed. Similarly, a balancing loop BX is also formed in the Effect Of Delivery Delay On Sales Effectiveness of the market sector. The balancing loops introduced will be discussed in detail in the following chapter while documenting the development of the ILE and the associated scaffolding.

2.7 Conclusion

A short overview of the Market Growth Model has been discussed in this chapter. The model consists of a kernel component and a number of extensions. The kernel component consists of three major components- an order fulfilment component, a revenue generation component and sales force component, each governed by a negative feedback loop, interrelated in a single reinforcing loop. The order fulfilment component originates from order generation that depends on the Sales Force and Sales Effectiveness to its supply. The ratio between Order Rate and Shipment Rate also known as Bill to Book ratio and indicates the balance between the two which reflects the condition of the company. Revenue generation consists of the revenue stream originating form shipments, exponentially averaged to produce the Recent Revenue. A certain Fraction of Recent Revenue generated is allocated as the total Budget for the Sales Force and thus sets the Target Sales Force, given the Cost per Sales Representative. The Sales Force is the total number of sales representatives in the company.

The model extensions are the Market Sector the Open Loop Steady State Gain (OLSSG), Total Cumulative Profit, the Capacity Utilization and the effect of Delivery Delay on the Sales

Effectiveness. The market sector represents how a market saturation affects the Sales Effectiveness and hence the total market gain. OLSSG shows the overall growth or decay of the market. The Capacity Utilization component shows how Delivery Delay affects the Shipment Rate. The market impact component represents how the market responds with respect to the Sales Effectiveness to a change in the Delivery Delay Perceived by the market. Each part of the model is scaffolded and discussed in detail in the following chapter.

CHAPTER THREE: SCAFFOLDING THE MARKET GROWTH MODEL

3.1 Introduction

The previous chapter describes the structural concept of the market growth model in brief. In this chapter the focus will be on the computer-based scaffolding designed to understand the market growth model as a case for building an Interactive Learning Environment (ILE). Computer-based scaffolding has been used as the computer-based support for helping students to gain the skills at doing tasks that are beyond their unassisted abilities (Belland, 2014; Hannafin, Land, & Oliver, 1999; Quintana et al., 2004). The Interface mode of Stella Architect software has been used for the scaffolding purpose. The work that the learner is facing is progressing more or less as guided in the original assignment. Problems given there have been considered step by step with the associated descriptions. The detailed work presented in this Interactive Learning Environment (ILE) by way of story-telling in Stella Architect is presented in appendices of this thesis.

The Scaffolding of Market Growth learning experience is done as the development of model and the associated analysis as the tasks are progressing. There are basically two parts in the assignment. The first part concerns the kernel model and its behaviour, a model that is subsequently extended with the limited market sector and with the optimization of the workforce with respect to the profit. The second part of the assignment concerns the shipping capacity of the company, its utilization, the consequent delivery delay and its effect on capacity building and on the market demand (by way of the Sales Effectiveness). The case is about a company that produces and ships a high-tech product (artery stents) based on the orders. The company is intent not to learn from start-up problem experiences faced earlier by its competitors, - as expressed by a variety of reference modes of behaviour. The two main questions raised by the entrepreneurs are:

1. *What is the origin of the oscillations in Order Rate and Backlog that competitors have experienced, given the relatively smooth, S-shaped development in Sales Force and Capacity?*
2. *What is the mechanism for determining the optimal size of the Sales Force, - is it based on a global optimization and is the equilibrium attained optimal?*

3.2 The Basic Market Model

In first section, the model components were described with the equations. The Interactive Learning environment focuses on the behaviour analysis with reference to the underlying structure. For that purpose, the learning is invited to conduct a number of experiments that uncover the intimate relationship between structure and behaviour. In particular, the learner is invited to make changes in the values of certain parameters that happen to change the gains of the loops in the model and to observe and explain the consequent behaviour. The model is presented in steps in accordance with the principle of graduated complexity. Stock and flow diagram that represents the following assumptions:

a. *The Sales Force has a certain base effectiveness. Initially, each sales representative sells 4 batches of stents per month. (As the market saturates, their effectiveness is reduced, - a fact we will return to shortly).*
b. *Orders pile up in a backlog and the normal delivery time is 2 months. This defines the desired delivery rate.*
c. *You are being told that there are no capacity constraints, so the shipment rate corresponds to the desired delivery rate.*
d. *The revenues arise from sales and is determined by the fixed unit price, 10 000 EURO / batch of stents. The revenues are reported with a first order 3 months exponential delay.*
e. *As a staffing policy, 20%, of the reported revenues, will be spent on salaries for sales representatives. The unit salary for a sales representative is 8000 EURO / month.*
f. *The number of sales representatives is being adjusted to the affordable level with a first order 18 months delay.*

A step by step review of the graduated complexity presented and the associated scaffolding facilitated in Stella Architect is presented below:

3.2.1 Order Rate

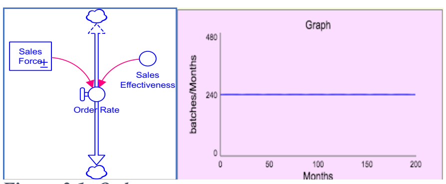


Figure 3.1: Order rate

Sales Force with its certain effectiveness creates the Order Rate. The number of orders generated per time unit determines the internal dynamics of the company, the Backlog accumulated, the Shipment Rate produced, the Revenue collected, and the Budget allocated to support a Target Sales Force determining the Sales Force next time around.

The Order Rate is a flow here and is defined with the formula,

Order Rate= Sales Force * Sales Effectiveness

Initially, the Sales Force is fixed to 60 persons and the value of Sales Effectiveness is set at 4 batches of stents per person per month. The Order Rate is thus 240 batches of stents per person per month.

3.2.2 Backlog

The Orders are accumulated in a Backlog- a stock that represents the number of orders collected to be honoured by way of shipments. Accumulation is a time-consuming process implying that relates the current state (level) of the stock accumulating to its former state and the rates governing the associated flows. Consequently, the Backlog can be calculated as:

Backlog (t) = Backlog (t - dt) + (Order Rate - Shipment Rate) * dt.

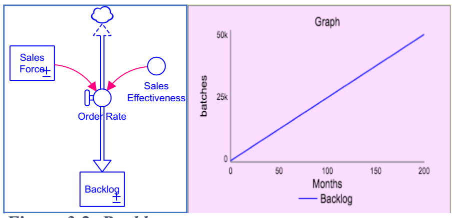


Figure 3.2: Backlog

If there is no any outflow, the Order Rate will be accumulated and deposited in the Backlog. The result of a constant Order Rate is the linear increase in the Backlog. Note that, in general, the behaviour of the order rate transforms into a very different behaviour characterizing the Backlog. Here, say, the behaviour produced is linear growth because there is no outflow yet and the rate of Orders is constant. The Backlog is initialized at 480 batches of stents (to cater for a subsequent equilibrium condition).

The learner may change the Sales Effectiveness so as to modify the Order Rate and thus the steepness (rate of change) of the Backlog trajectory.

3.2.3 Shipment Rate

Stocks are changed both by inflows and outflows. With a constant rate of outflow, it is possible to calculate how long it will take to empty a stock. The time it takes to deplete a stock at the current outflow rate is equal to the current stock value divided by that rate. Since, the process of accumulation (or decumulation) in stock level is the main characteristics of the dynamics of complex systems. It is important for learners to comprehend the relationship between flow rates and stock levels. When the rates of outflows are subtracted from the rates of inflows, the result is the net rate of the flow. A positive net rate causes the stock to increase, a negative net rate causes the stock to decrease, a net rate equal to 0 causes no change (no dynamics). The process graphical portraying and analyzing the development of a stock level over time along with the constituent flow rates is called the graphical integration and is an important skill to be acquired by learners. Consequently, such graphs are incorporated in the learning environment.

Inflows and outflows are given over the time interval from t-dt to t. The net flow over the preceding time interval is added to the previous stock value at time t-dt to produce the current stock value at time t. The total change over the time interval is equal to the net flow times the length of the time interval dt.

Disregarding other disturbances, there is the amount of minimum time taken for the management of orders to be shipped is the delay time (Sterman 2000). Normal Delivery Delay is given as 2 months, which means it normally takes two months to prepare (produce) and deliver an Order. The Desired Shipment Rate is determined by the Backlog and the Normal Delivery Delay as:

Desired Shipment Rate

=

Backlog / Normal Delivery Delay (batches / month)

There are currently no production and/or shipment constraints, therefore;

Shipment Rate

=

Desired Shipment Rate (batches / month)

The actual average delay in delivering orders (the mean residence time of orders in the backlog) is given by:

Delivery Delay

=

Backlog/Shipment Rate

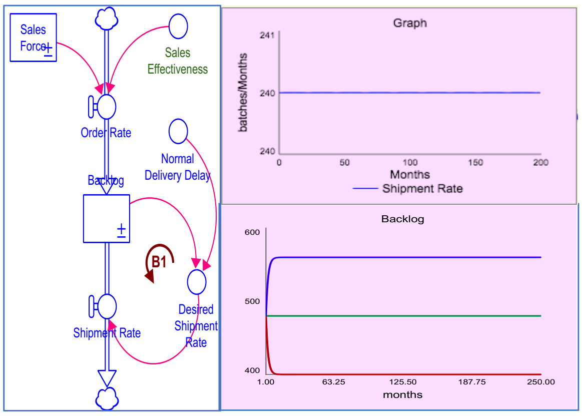


Figure 3.3: Shipment, Backlog and Delivery delay

As the Shipment Rate reflects the Desired Shipment Rate that responds to the Backlog and the Normal Delivery Delay Time, a first order balancing loop, B1, is thus formed. Over time, it serves the purpose of bringing the Shipment Rate in line with the Order Rate. It generates goal seeking behaviour: causing the Shipment Rate to approach the Order Rate and Backlog to approach a value corresponding to the Order Rate times the Normal Delivery Delay Time. Since, initially, there are 480 Orders in the Backlog, and the Normal Delivery time is 2 months, the Shipment Rate is initially 240 (i.e. 480 / 2), corresponding to the Order Rate (when the Sales Force is 60 and the Sales Effectiveness is 4). By increasing or decreasing the Sales Effectiveness, a dis-equilibrium arises. Due to the feedback loop B1, the system then undergoes a transient development towards a new equilibrium. The ILE has been designed so as to portray this transient. Two graphs on the flow rates as well as the stock (Backlog) illustrates all potential transients that may arise (as well as a potential equliibrium). If the Order Rate is initially 240, the system is in equilibrium at that time. If the Sales Effectiveness is above 4, then the Order Rate is larger than the initial Shipping Rate. Consequently, the Backlog increases and so does the Shipping Rate, so as to, finally approach to the Order Rate. The

reverse dynamics results from an Order Rate smaller than the initial Shipment Rate, say 180, produced by a Sales Effectiveness of 3. The Shipment Rate, consequently, decreases so, again, as to approach the Order Rate.
The delay in the loop B1, causing a first order converging pattern of behaviour between Order Rate and Shipment Rate, is effectively portrayed in slide 4 and 5 in the ILE.

3.2.4 Revenue Generation

Revenue is the function of the Shipment Rate and Price of the product in euros/months unit.

$$\text{Revenue} = \text{Price} * \text{Shipment Rate}$$

The Revenues generated from shipments is reported with a first order 3 months exponential delay as:

$$\text{Recent Revenue}(t) = \text{Recent Revenue}(t - dt) + (\text{Change in Recent Revenue}) * dt$$

Where, Recent Revenue is initialized by the Revenue itself and Change in Recent Revenue is defined as;

$$\text{Change in Recent Revenue} = (\text{Revenue} - \text{Recent Revenue}) / \text{Revenue Reporting Delay}$$

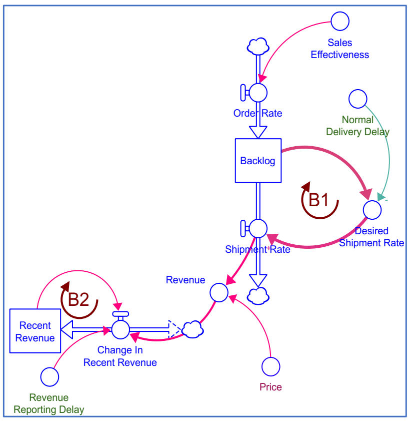


Figure 3.4: Revenue generation

Consequently, a first order balancing loop, B2, is thus formed. Over time, this loop serves the purpose of smoothing the Revenue, i.e. bringing the Recent Revenue in line with the current Revenue. The Price here is exogenous to the system and fixed as 10000 Euro per batch. A change in price would change in the amount of Revenue generated, but not in the pattern of the behaviour produced by the model so far as demonstrated in the graph below. The pattern characterizing the Revenue behaviour is a reflection of the Backlog response of a changed Order Rate resulting from a change in the Sales Effectiveness and the pattern characterizing the Recent Revenue is reflecting the additional delay caused by the smoothing process of the loop B2, (fig 3.5) below:

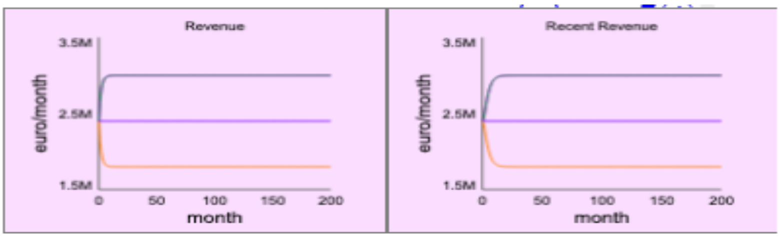


Fig 3.5:- Revenue and Recent Revenue with Sales Effectiveness 3, 4 and 5.

Whether the Order Rate causes the Shipment Rate to increase or decrease, then the Revenue will follow instantaneously. For example, the Recent Revenue will follow with an exponential convergence towards the Revenue with the delay of 3 months, when there is a decrease in the Shipment Rate.

The delay in loop B2 causing a first order converging pattern of behaviour between Revenue and Recent Revenue, is effectively portrayed in slide 6 and 7 in the ILE.

3.2.5 Sales Budget and Target Sales Force

The number of sales representatives that the company can support is determined by the Sales Budget which is taken as the total Cost of Sales Representatives. The Reported Revenue is the only source for the Budget allocation. Since, 20% of the Reported Revenue is allocated to the total cost of the Sales Force, the Fraction Revenue to Sales becomes 0.2 and the Sales Budget is defined as,

Sales Budget

=

Fraction Revenue to Sales * Recent Revenue.

To maintain the Sales Force at a level consistent with the company´s financial situation, determined, in part by the Sales Force itself. A Target Sales Force is defined as the Sales Force that the company´s finances can sustain. The Target Sales Force is defined, based on the Sales Budget (a portion of the Recent Revenue) and the Cost per Sales Representative;

Target Sales Force

=

Sales Budget / Cost per Sales Representative;

Where, Cost Per Sales Representative is a parameter, set at 8000 euro per salesperson per month.

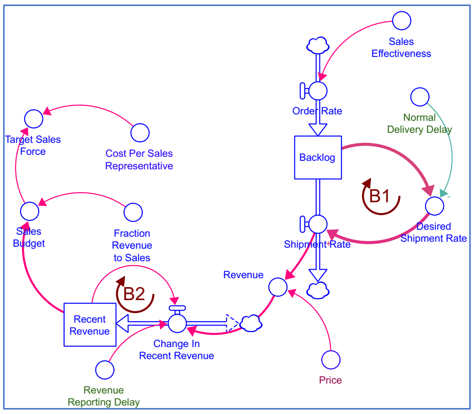


Figure 3.6: Target Sales Force calculation

3.2.6 Closing the Sales Force loop

The actual Sales Force adjusts towards the Target Sales Force by the way of the Sales Force Net Hiring Rate, a first order adjustment. The Adjustment Time for the Sales Force represents the time required to recognize and fill vacancies and for the new salesperson to become fully effective. The flow associates with the Sales Force, i.e. Sales Force Net Hiring Rate is thus defined as the difference between the Target Sales Force and actual Sales Force distributed across the Sales Force Adjustment Time, set to 18 months.

Since, the Sales Force itself feeds back to Sales Force Net Hiring Rate, a first order balancing loop, B3, is thus formed. Over time, it serves the purpose of bringing the Sales Force in line with the Target Sales Force.

$$\text{Sales Force}(t) = \text{Sales Force}(t-dt) + (\text{Sales Force Net Hiring Rate}) * dt.$$

where,

$$\text{Sales Force Net Hiring Rate} = (\text{Target Sales Force} - \text{Sales Force}) / \text{Sales Force Adjustment Time}$$

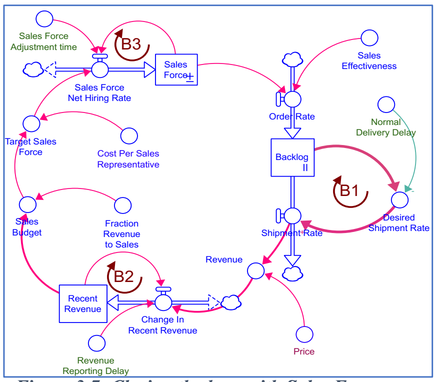


Figure 3.7: Closing the loop with Sales Force

Having closed the loop, the behaviour of the model changes radically. This major loop, R1, is traditionally considered a reinforcing loop. As we will see, it may produce three different modes of behaviour as;

- a divergent behaviour,
- an equilibrium, and
- a convergent behaviour

The behaviour mode produced by the loop is characterized by the four parameters;

- Sales Effectiveness,
- Price,
- Fraction of Revenues to Sales, and
- Cost per Sales Representative.

The specific behaviour is additionally, determined by the parameters;

- Normal Delivery Delay,
- Revenue Reporting Delay, and
- Salesforce Adjustment Time.

The learners are challenged to understand the relationship between the quadruple of the first four parameter values and the resulting behaviour modes and between the triplet of the three last parameter values and the specific nature of the behaviour produced. This is accomplished by means of referring to the Steady State Gain (SSG) and the Transient Gain Component (TGC).

Behaviour mode analysis by means of the Steady State Gain and the Transient Gain Components:

To facilitate the analysis, the Steady State Gain is defined as the product of four parameters:

SSG

=

Sales Effectiveness * Price * Fraction of Revenues to Sales * (1-Cost per Sales Representative)

when SSG=1, the Targe Sales Force takes on a value of the Sales Force that predicted the Shipment Rate and Recent Revenue to support the current Targe Sales Force. With that, the Sales Force does not change and the system remains in equilibrium. At the outset;

- Sales Effectiveness = 4;
- Price =10 000;
- Fraction of Revenues to Sales = 0.2; and
- Cost per Sales Representative = 8 000.

so that SSG =1, and the system is in equilibrium. A modification of this quadruple of values that causes SSG to be larger than 1, will cause a divergent behaviour (growth). A modification that causes SSG to be smaller than 1, will cause a convergent behaviour (decay).

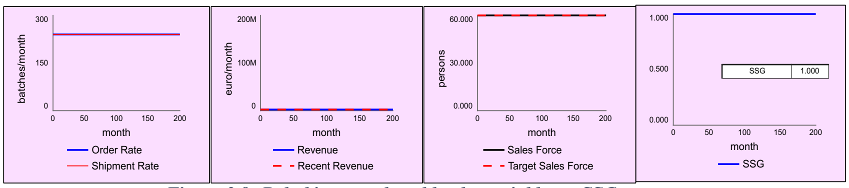


Figure 3.8: Behabiour produced by the variables at SSC

In slide 10, the learners are challenged to experiment with a variety of values for the parameters defining the SSG and analyze the consequences of their actions. In general, larger parameter values provides a reinforcement of the prevailing mode of behaviour, whether it is divergent or convergent. Consequently, the SSG provides an indicator defined on a numerical scale, from 0 to 1 and beyond, of the impact that the loop R1 has on the model behaviour.

To further enhance the analysis, the Transient Gain Component are defined as the ratio between the target (goal) of each of the three negative feedback loops and the state produced by each of them, - a ratio is determined by the three adjustment time parameter values;

- Normal Delivery Delay,
- Revenue Reporting Delay, and
- Salesforce Adjustment Time.

Consequently, the three Transient Gain Components are;

- TGC1 = Shipment Rate/ Order Rate
- TGC2 = Recent Revenue/ Revenue and
- TGC3 =Sales Force and Targe Sales Force

When employed in the analysis, observe that the Transient Gain Component represents reaction to the prevailing behaviour that is governed by the loop R1. Consequently, when SSG > 1i. i.e. when the model produces a divergent behaviour, then all the Transient Gain Components take values below 1. In that case, an increase in the adjustment time associated with one of the Transient Gain Components (i.e. any of the balancing loops), on the other hand, leads to a larger TGC, causing a reinforcement (a speed-up) of the divergence.

Correspondingly, when the SSG <1, i.e. when the model produces a convergent behaviour, then all Transient Gain Components take values above 1. In that case, an increase in the adjustment time associated with one of the Transient Gain Components (i.e. any of the balancing loop), leads to a larger TGC, causing an attenuation (a slow-down) of the convergence. A reduction in the adjustment time, associated with a Transient Gain Component (i.e. any of the balancing loops), on the other hand, leads to a smaller TGC, causing a reinforcement (a speed-up) of the convergence.

When SSG = 1, i.e. when the model is in equilibrium, then the Transient Gain Component takes the value 1 and are immaterial or inconsequential.

In conclusion, a change in any of the Transient Gain Component does not cause a change in the mode of behaviour produced, but in the aggressiveness with which that mode of behaviour is expressed in the model behaviour.

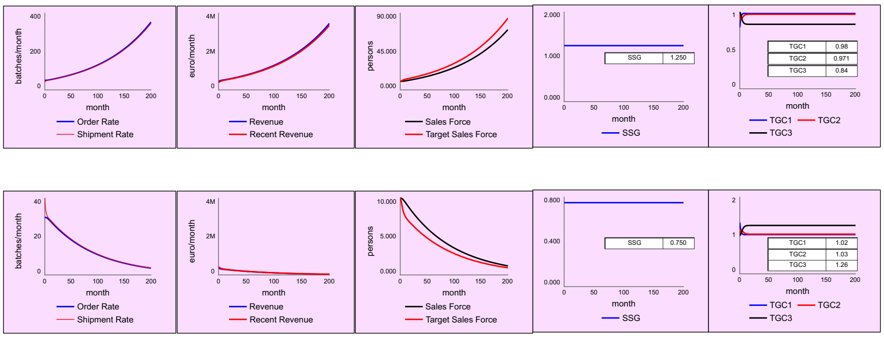


Figure 3.9: Behabiour produced by the variables at below and above the SSC

In slide 11, the learners are challenged to experience to experiment not only with a variety of values for the parameters defining the SSG, but also with the parameter determining the Transient Gain Component and, again, to analyze the consequences of their actions. consequently, the Transient Gain Component provides an indicator defined on a numerical scale, from 0 to 1 and beyond, of the impact that the balancing loops B1, B2 and B3 have on the model behaviour.

3.2.7 *Variable Sales Effectiveness*

The Sales Effectiveness is one of the four parameters that determines the Steady State Gain in the model, and one that will be subject to endogenization in this case study. Consequently, when experimenting with the model at this stage in the study, doing so subject to the Sales Effectiveness is a scaffolding activity. It prepares the learner for the endogenization. So far, that experimentation has been limited to constant values at, over and below the value 4. The next stage in such a scaffolding process is to investigate the systems response to linear changes in the Sales Effectiveness.

For this purpose, an Initial and a Final Sales Effectiveness, -are being defined, each with range from 3 to 5 (where the range may vary). The model structure allows the Sales Effectiveness to develop linearly between those two extremes by defining Sales Effectiveness as:

(Initial Sales Effectiveness- (Initial Sales Effectiveness -Final Sales Effectiveness) *MIN (TIME/STOPTIME, 1))

The experimental combinations of Initial and Final Sales Effectiveness proposed to the learner are;

1) Initial 4 and Final 5,

2) Initial 3 and Final 5,

3) Initial 4 and Final 3,

4) Initial 5 and Final 3,

5) Initial 3 and Final 4 and

6) Initial 5 and Final 4.

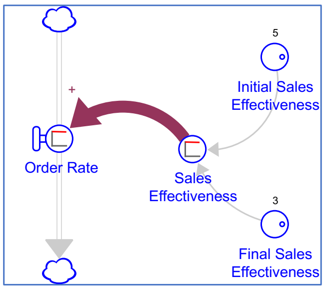


Figure 3.10: Uneven Sales Effectiveness

By allowing the values for both the Initial and the Final Sales Effectiveness range between 3 to 5, we observe the following behaviour patterns resulting:

1. Linear growth in Sales Effectiveness started from 4 to 5 causes super exponential growth in the Order Rate, Shipment Rate, Revenue, Recent Revenue and Target Sales Force and Sales Force. The pattern of behaviour may be explained with reference to the linearly increasing Steady State Gain (SSG) above 1.

The growth is slightly tempered by the Transient Gain Components (TGCs) decreasing to values ever more below 1.

Figure 3.11: Sales Effectiveness increasing from 4 to 5

2. Linear growth in Sales Effectiveness from 3 to 4 causes a sub-exponential decay in the Order Rate, Shipment Rate, Revenue, Recent Revenue and Target Sales Force and Sales Force. The pattern of behaviour may be explained with reference to the linearly increasing Steady State Gain (SSG) from a value less than 1 towards 1. The decay is gradually tempered by the Transient Gain Components (TGCs) decreasing even more from values above 1 towards 1.

Figure 3.12: Sales Effectiveness increasing from 3 to 4

3. Combining 1 and 2 yields a linear growth in Sales Effectiveness from 3 to 5 causing sub-exponential decay followed by a super-exponential growth in the Order Rate, Shipment Rate, Revenue, Recent Revenue, Target Sales Force and Sales Force. Once more, the pattern of behaviour may be explained by reference to the linearrly inreasing Steady State Gain (SSG) from a value less than 1 towards 1 and beyond. The initial decay is gradually tempered by the Transient Gain Components (TGCs) decreasing even more from values above 1 towards 1. Subsequently, the growth that follows is tempered ever more by the same TGCs degreasing ever more below 1.

Figure 3.13: Sales Effectiveness increasing from 3 to 5

4. In very same way, the learner may develop an understanding of the impact of the Sales Effectiveness when allowing its value to change linearly from an initial value of 5, via the value of 4, towards a value of 3. Again, the result may be interpreted by way of the Steady State Gain (SSG), governing the behaviour mode, and the Transient Gain Components (TGCs) tempering the dynamics. Here, the pattern of behaviour may be explained by reference to the linearrly decreasing Steady State Gain (SSG) from a value more than 1 towards 1 and beyond. The initial growth is gradually tempered by the Transient Gain Components (TGCs) is increasing from values below 1 towards 1and beyond.

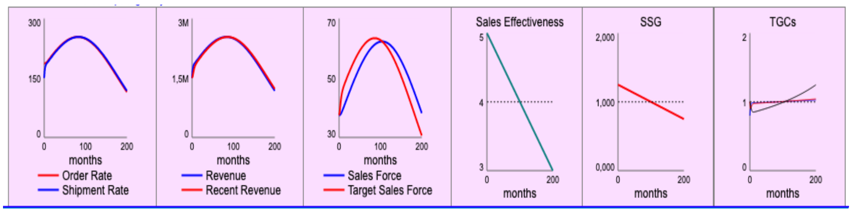


Figure 3.14: Sales Effectiveness increasing from 5 to 3

3.3 The Dynamic Market (Task V and VI)

So far, we have considered the Sales Effectiveness to be an exogenous , - i.e. a parameter that may be influenced at will. Such a change will cause a change in the Steady State Gain of the model and will thus modify the behaviour of the system. The assumptions associated with a constant Sales Effectiveness are;

a. There is an unlimited market size and access, and so that the Sales Effectiveness is not affected by any kind of market saturation or boundaries against market entry, leaving the size of the Sales Forces is the factor limiting the sales (i.e. Order Rate).
b. There are no production constraints. The company can produce and ship as many batches of stents to satisfy the Order Rate so that the products are shipped with a Normal Delivery Delay.

In reality, the market and access to it is limited. So is the production and shipping capacity. While as the Sales Effectiveness may be affected by a number of factors, say the quality of the sales representatives, hired, the main concern here is the effect of the market, specifically its size. If there are more sales representatives than the market can “absorb” so that the sales representatives of a single company are cannibalizing each other, then the Sales Effectiveness decreases. In this model, the market factors that impact the Sales Effectiveness through the interaction with the Sales Force are the Market Sales Potential, the Reference Sales Potential and the Reference Sales Effectiveness:

3.3.1 Endogenous Sales Effectiveness

In reality, the Sales Force acts in a market with a Sales Effectiveness that is determined by the resistance to the sales effort by the sales representatives, - a resistance defined by the market. That resistance to the sales effort, and thus the corresponding reduction in Sales Effectiveness, is determined by the size of the Sales Force as well as the Market Sales Potential, - the large the Sales Force as compared to the Market Sales Potential, the more resistance the Sales Representatives are being met with. In this section, we intend to incorporate the limiting structures to capture the Sales Effectiveness caused by a limited market. The Sales Effectiveness is the Reference Sales Effectiveness, modified by the Effect of the Market Saturation on the Sales Effectiveness.

The Sales Effectiveness is the Reference Sales Effectiveness, modified by the Effect of the Market Saturation on the Sales Effectiveness. So the Sales Effectiveness depends on the market saturation.

Sales Effectiveness

=

Reference Sales Effectiveness

*

Effect of Market Saturation on Sales Effectiveness

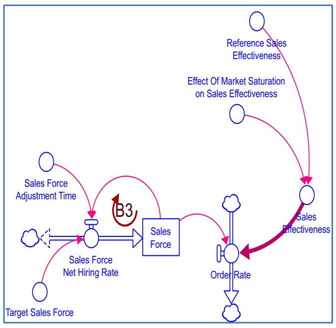


Figure 3.15: Limits to Sales Effectiveness

The Reference Sales Effectiveness is the maximum Sales Effectiveness, set here at 10 batches per month and attained when the Reference Sales Potential is very small compared to the Market Sales Potential, - e.g. when there is a single sales representative operating in the market. When the Sales Force is very small, there is no internal "competition" between the sales representatives; they are not aiming at the same target customer base.

As the Sales Force grows and thus the Reference Sales Potential approach the Market Sales Potential, the Sales Effectiveness falls. The market saturation refers to the Reference Sales Potential of the Sales Force relative to the Market Sales Potential, - normalized to a number between 0 and 1. The Effect of the Market Saturation on Sales Effectiveness has been estimated to be a linear function of the Market Saturation and is expressed as;

Function of the Market Saturation and is expressed as;

Effect of the Market Saturation on Sales Effectiveness

=

MAX

(1-Reference Sales Potential/

Market Sales Potential, 0)

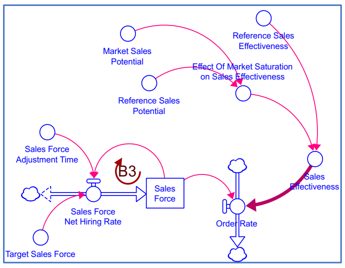
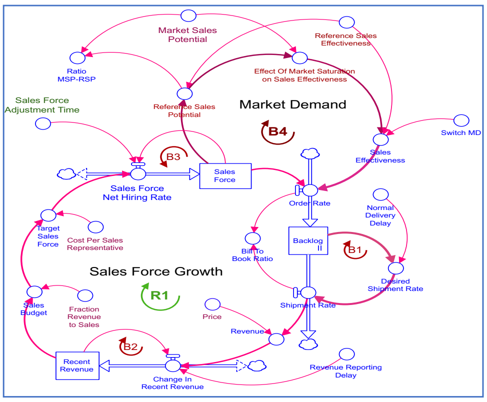


Figure 3.16: Market Potential

The Reference Sales Potential is the full potentiality of the market and is calculated as the Sales Force multiplied by Reference Sales Effectiveness. Finally, the Reference Sales Potential is the Sales Potential that the Sales Force would have had if each sales representative had operated with the Reference (Max) Sales Effectiveness. The Reference Sales Potential thus existing if all the sales representatives worked under such ideal condition is thus;



Reference Sales Potential

=

Sales Force *Reference Sales Effectiveness

The structure of the market and its effect on the Sales Effectiveness is documented to the learner in Slide 1 – 9 in the ILE (Story 2 V & VI).

Figure 3.17: ***Extended Market Growth Model***

This market growth model including the extended market structure endogenizes the Sales Effectiveness and introduces a major balancing loop (B4) in the system. This loop counteracts the reinforcing behaviour resulting from loop R1 whether its gain is larger or smaller than 1. The major reinforcing loop R1 originally responded to the unlimited Market Sales Potential with unlimited growth. In the face of a limited Market Sales Potential, however, B4 regulates the Sales Effectiveness so as to approach the value 4 and thus the Steady State Gain of R1 to approach a value of 1, whereby the Order Rate, Shipment Rate, Revenue and Sales Budget generated is sufficient to entertain the current Sales Force . Consequently, any growth in the Sales Force has two partial effects that offset each other. On the one hand, it influences the Order Rate positively so that, assuming a constant Sales Effectiveness, the Order Rate would increase. This mechanism is caused by the reinforcing loop R1 relating Sales Force directly to the Order Rate. On the other hand, it would cause the Reference Sales Potential to increase so as to increase the market saturation. That will induce an Effect of Market Saturation causing the Sales Effectiveness to decrease and the Order Rate to be influenced negatively. This mechanism is caused by the balancing loop B4 indirectly (via the market) relating Sales Force to the Order Rate.

After simulating the model by taking Market Sales Potential as 6000 unit and Reference Sales Effectiveness as 10 unit and keeping other parameters same as in the previous model, the model produces the goal seeking behaviour in the system.

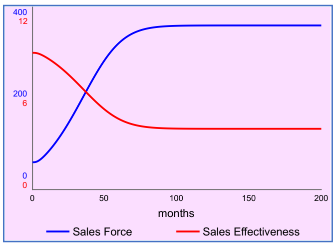


Figure 3.18: Exponential growth smoothed by the loop B4

As is illustrated in Figure 3.18, therefore, a growth in the Sales Force causes a decrease in the Sales Effectiveness and is brought to a standstill and so the model is brought to an equilibrium. The simulation results above, demonstrates the initial exponential growth, - when R1 dominates the system. Later, B4 dominates the system and gradually produces goal seeking behaviour until Sales Force stabilize at 360 as Sales Effectiveness declines from 9 to 4. The same equilibrating mechanism comes into action if the Sales Force is initialized at a value larger than its equilibrium value.

Slide 10 in the ILE (Story 2 V&VI) allows for the learners to experiment with initial Sales Force values below and above the equilibrium value reached when the Feraction of Revenues to Sales = 0.2, causing the Sales Effectiveness to approach 4 causing the Steady State Gain to approach 1.

The experimentation by learners with that fraction in slide 10 of the ILE, yields remarkable results (often considered counter -intuitive): Assume that the model is initiated in equilibrium with the Fraction Of Revenue To Sales initiated at 0.2. Assume, moreover, that the Fraction of revenue to Sales is being increased, causing the Steady State Gain to start above 1 and thus the Sales Force to increase. Arguing from the perspective of loop R1, this should cause the Order Rate to increase so as to initiate growth. Arguing from the perspective of the loop B4, however, that should cause the Sales Effectiveness to drop so as to counteract the growth in Sales Force. The question is thus what is the most dominant loop? In fact, the learner will experience that the Sales Effectiveness decreases so much that it compensates for the growth in Sales Force so that the Order Rate drops, - e.g. that loop B4 dominates when the Fraction Of Revenues To Sales is being increased beyond 0,2. Correspondingly, a decrease in the Fraction Of Revenues To Sales from 0.2 towards, say, around 0.15 will cause a drop in the Sales Force. As a consequence, the Sales Effectiveness will grow, causing an increase in the Order Rate. A drop beyond that value causes a decrease in the Sales Force that more than compensates for the increase in the Sales Effectiveness. So here we see that the dominance of B4 is challenged and overtaken by the loop R1.

When OLSSG >1, R1 tends to develop unlimited growth potential in the market. With a fixed (limited) market potential, B4 reduces the Sales Effectiveness as the Sales Force grows. Gradually, this negative impact on the Order Rate compensates for the positive impact resulting from the growth in the Sales Force. The result is a dampening of the growth in the Order Rate and thus the Shipment Rate and the Target Sales Force.

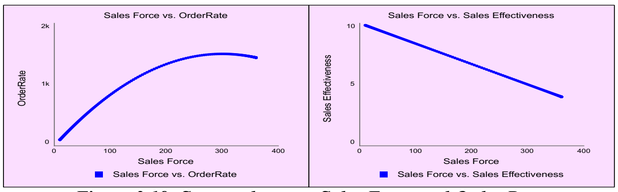


Figure 3.19: Synergy between Sales Force and Order Rate

3.3.2 Initializing the Backlog in Steady State

The relationship between the Sales Effectiveness, the Price, the Fraction of Revenues to Sales, and the Cost per Sales Representative altogether make up the Steady State gain (SSG). If the value of one of these parameter change, then one or more of the others must do so as well in order to retain the steady state condition (SSG = 1). This can done by an endogenous adjustment of the Sales Effectiveness to the values of all the other parameters defining SSG. On the other hand, for any value of Sales Effectiveness, the values of the other parameters can be set so as to define the SSG altogether.

When the Backlog influences the Sales Effectiveness through the loop B4, it determines the OLSSG in the loop R1. So, a steady state can only be obtained when the Backlog is in equilibrium condition i.e.;

$$\text{Order Rate} = \text{Shipment Rate}$$

Substituting the expressions for Order Rate and Shipment Rate so that both are dependent on Backlog and solve the resulting equation for Backlog yields:

Order Rate

=

Sales Force * Sales Effectiveness

Where,

Sales Effectiveness

=

(1- Sales Force * Reference Sales Effectiveness / Market Sales Potential)

Note that, in steady state;

Sales Force

=

Shipment Rate * Price * Fraction of Revenue to Sales / Cost Per Sales Representative

=

Shipment Rate * A / Reference Sales Effectiveness

Where,

A

=

Price * Fraction of Revenue to Sales * Reference Sales Effectiveness /

Cost per Sales Representative

So,

Order Rate

=

Sales Force * (1- Sales Force * Reference Sales Effectiveness / 2)

Market Sales Potential)

=

Shipment Rate * (A / Reference Sale Effectiveness) *

(1 - Shipment Rate *A / Market Sales Potential)

=

Shipment Rate

Therefore;

((A/ Reference Sales Effectiveness) - Shipment Rate *A^2 /

(Reference Sales Effectiveness * Market Sale Potential))

=

1

Also,

Shipment Rate = Backlog / Normal Delivery Delay

So that;

Shipment Rate

=

Backlog / Normal Delivery Delay

=

(A-1) * Market Sales Potential / A^2

And

Backlog

=

(A-1) * Market Sales Potential * Normal Delivery Delay / A^2

Note that the initial Backlog always balances the Sales Force so as to initialize the model in steady state. Slides 11-12 (Story 2 V&VI) introduces the learner to the analytic initialization of the Backlog in equilibrium, - given the values of the parameter values defining the market condition as well as parameters defining the Steady State Gain (SSG).

Slide 13 (Story 2 V&VI) allows the learner to experiment with a variety of initial Backlog values to confirm that the model returns to the same equilibrium condition, given the parameters concerned.

The learner should, however, also realize that there are many potential equilibria, each defined by a combination of the parameter values of concern. For example;

Parameters	**Condition 1**	**Condition 2**	**Condition 3**	**Condition 4**	**Condition 5**
Price	10000	10000	10000	12000	8000
Fra. Revenue to Sales	0.2	0.2	0.15	0.25	0.2
Cost per Sales Repre.	8000	6000	6000	10000	8000

When we try other possible combinations for these values to find other equilibrium conditions for this system, all the combinations eventually give the equilibrium condition to the system because of the endogenization of the Sales Effectiveness by the market.

Slide 14 (Story 2 V&VI) allows for the learner to conduct such an experiment, focused on the Fraction of Revenue To Sales.

3.3.3 The First Trade off

The balancing loop (B_4) is the major loop in the system that controls the behaviour resulting from loop R_1 by way of the Sales Effectiveness and thus the SSG . The Market Sales Potential and the Reference Sales Effectiveness are the parameters that determine how the Sales Force influences the Sales Effectiveness by the way of the Reference Sales Potential and the effect that potential has on the Sales Effectiveness. We established that there is a trade-off between the Sales Force and the Sales Effectiveness. Up to a certain point, an increase in the Sales Force compensates for the corresponding decrease in Sales Effectiveness so as to cause the Order

Rate to increase. Thereafter, an additional increase in the Sales Force causes the Sales Effectiveness to decrease to such an extent that the Order Rate decreases. So, when identifying the Sales Force that yields the largest Order Rate, one must take this trade-off into consideration. Slide 15 in the ILE (Story 2 V&VI) discusses this trade-off as a result of the synergy between loops R1 and B4. Slide 16 in the ILE (Story 2 V&IV) allows for the learner to experience this trade-off by modifying the Sales Force Exogenously, to observe the counteracting response in the Sales Force and the Sales Effectiveness as well as the resulting Order Rate, reaching a maximum as the Sales Force passes 300. This is scaffolding the learner for an in-depth analysis of this first trade-off.

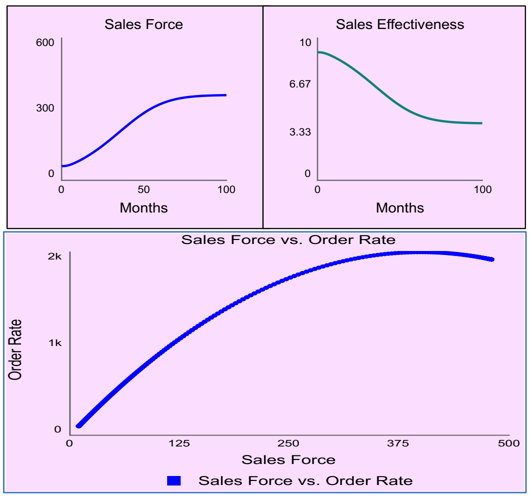


Figure 3.20: Visualizing the trade-off between Sales Fore and Sales Effectiveness resulting in Order Rate

When the Sales Force is relatively small and the Sales Effectiveness is relatively large, the loop R1 dominates: The resulting increase in Order Rate causes the Revenue, Sales Budget, and Target Sales Force to grow, causing a growth also in the Sales Force, - resulting in an even larger Order Rate. This happens as long as the growth in Sales Force is not compensated by the decline in the Sales Effectiveness. When that takes place, however, the loop B4 dominates by way of the Effect of Market Saturation On Sales Effectiveness. This is the mechanism that brings growth to a halt: When the direct effect that an increasing Sales Force has on the Order Rate, is fully offset by the effect that the market saturation has on the Sales Effectiveness, then the Order Rate, the Revenues, the Sales Budget and the Target Sales Force grows no more and

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Deleted: ***Exponential***

Deleted: ***growth***

Deleted: ***smoothed by the loop B4***

they have all reached a maximum. If, in this state, the steady state condition is being satisfied (SSG = 1), then the system will remain in this optimal state.

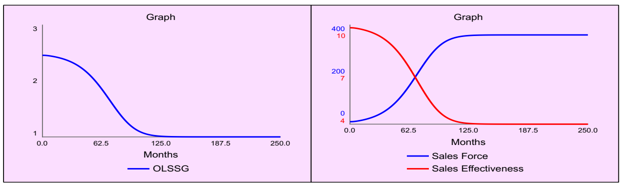


Figure 3.21: Trade off: OLSSG, Sales Effectiveness and Sales Force

When, on the other hand, the Sales Force is excessively large, then the Sales Effectveness is very small and the Order Rate generated is not sufficient to support the large Sales Force. Consequently, the Sales Force diminishes while as the Sales Effectiveness increases so as to bring the SSG from a value below 1 up towards 1. At some point of time, the SSG reaches the value 1 and the system equilibrates after a transition.

After the initial numerical and graphical scaffolding, the learners are, in Slides 17 in the ILE (Story 2 V&VI) exposed to the mathematical identification of the optimal value for the Sales Force with respect to the Order Rate (the value for the Sales Rate that maximizes the Order Rate:

Expressing the Order rate as a function of Sales Forces yields, as we have seen;

Order Rate
=
Sales Force *
(1- Sales Force * Reference Sales Effectiveness /
Market Sales Potential)

Taking the derivative of the Order Rate with respect to the Sales Force and introduce the first order condition;

d Order Rate / d Sales Force = 0,

to identify the optimal Sales Force (the one that maximizes the Order Rate):

d Order Rate / Sales Force

=

d (Sales Force - Sales Force " * Reference Sales Effectiveness /Market Sales Potential) / d Sales Force

=

1 - 2 * Sales Force * Reference Sales Effectiveness / Market Sales Potential

=

0

=>

Optimal Sales Force

=

(1/2) * Market Sales Potential / Reference Sales Effectiveness

=

(1/2) * 600 / 20 = 300

The result confirms the experimental findings of the learner obtained in Slide 16.

3.3.4 Optimization

It is important to consider the point when the Sales Force yields the largest Order Rate. It is also a fact that the Sales Force that produces the largest Order Rate is not necessarily the optimal one with respect to company Profit. In that regard, one must not only account for the trade-off between the Sales Force and the Sales Effectiveness but must also account for the costs incurred by the Sales Force: The larger the Sales Force, the larger are the costs with reference to the model we are working on.

In this section, we assume that the Fraction of Revenues allocated to entertain the Sales Force may be adjusted- one that leads to an Optimal Sales Force which finally maximizes the Profit for the company. Such a Sales Force will, implicitly cause the Sales Effectiveness to take on a corresponding optimal value. So, we need to find a policy which will show the exact amount of fraction of revenue to be allocated for the Sales Force in order to produce an Optimal Profit for the company.

3.3.4.1 Size of the Sales Force and Optimization of the Profit (The Second Trade Off).

To find the Sales Force with the account of all the costs producing Optimal Profit is the main task here. For that, we need to find out the Fraction of Revenue which leads to a certain level of Sales Force which finally maximizes the Profit.

Determinant of the Sales Force originally is mainly the Target Sales Force and hence the Cost per Sales Representative, Fraction Revenue to Sales and Price per unit sales. After inclusion of market sector, Reference Sales Effectiveness and Market Sales potential are the additional values to be included for the calculation for the Sales Force.

So, the optimal size of the Sales Force which gives the Optimal Profit is calculated as;

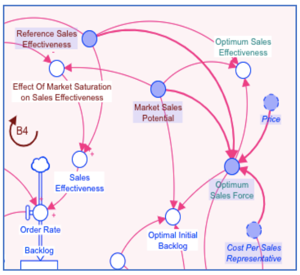


Figure 3.22: Optimum Sales Force

Optimum Sales Force

=

(1- Cost per Sales Representative/

(Price *Reference Sales Effectiveness)) *Market Sales

Potential / (2 *Reference Sales Effectiveness)

To find the real Optimum Budget allocation to the company for the gain of Optimum Profit we need to calculate the Optimum Fraction Revenue to Sales which will be the new Fraction Revenue to Sales and this is now calculated as;

Optimum Fraction Revenue to Sales

=

(Optimum Sales Force*Cost Per Sales

Representative)/Reported Revenue

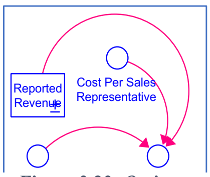


Figure 3.23: Optimum Fraction Revenues to Sales

Simulating the model with the Market Sales Potential 6000 and 8000 respectively we get the following behaviour of the Sales Force and Monthly Profit. In first case the Optimum Sales Force is 276 and in later case it is 368 and Monthly Profit in first case is 11.5 and in later case it is 15.4.

To see the difference in the model behaviour by the change in Fraction Revenue to Sales we set a number having value ranges from 0.10 to 0.30. We see the simulation with different Fraction values as shown in the table below. By increasing its value gradually from 0.14 towards 0.3, the simulation shows the difference in the value of the Sales Force and Monthly Profit. The figure shows the comparative values for the different values of Fraction Revenue to Sales between 0.14 to 0.24 randomly. The corresponding changes in the Sales force and Monthly Profit is seen.

Fraction Revenue to Sales	Sales Force	Monthly Profit (M)
0.14	255	12.6
0.15	279	12.7
0.16	300	12.6
0.20	360	11.5
0.22	382	10.8
0.24	400	10.1

Table 1: Fraction Revenue to Sales, Sales Force and Monthly Profit

It shows there is the possibility of having maximum profitability for the company. So, the further step for the modeller is to find out such optimum conditions where the profit gain will stay at that maximum point once obtained and the system remains at the steady state for that maximum point for the rest of its life. When we dropped down the value of Sales Effectiveness, the value of Sales Force increased and does same with the Monthly Profit. With the increase in Sales Force, Monthly Profit decreased. The following chart shows the results of the simulations for Monthly Profit.

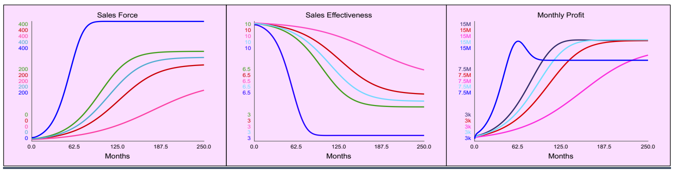


Figure 3.24: Fraction Revenue to Sales, Sales Force and Monthly Profit

The graphs in fig. 4.49 for the different fraction values have one common trait in the case of Monthly Profit. They reach at a maximum point once and then the market limits it to an average steady state value/condition.

In this point of experimentation, students are supposed to think about the result of the simulation for Sales Force, Sales Effectiveness, Backlog and OLSSG with each value while increasing it gradually. The system is in steady state in any case when the OLSSG =1. There might be other combinations of these variables which can make the system in steady state condition. The Optimal Sales Force gives the Optimal Fraction Revenue to Sales with the Cost per Sales Representative and the Revenue generated by the system.

The Order Rate might be convenient criterium for an optimization. The trade-off identifies, may be extended to encompass revenue versus costs, - i. e. profit. Associated with the Sales Rate (originating from the Order Rate) there is revenue and with the Sales Force there are associated costs.

In Slide 18 in the ILE (Story V&VI) this trade-off is discussed and a structure defining the profit stream by way of the profit per month as :

Monthly Profit = Revenue – Costs,

where Costs are defined as;

Costs = Sales Force * Cost Per Sales Representative.

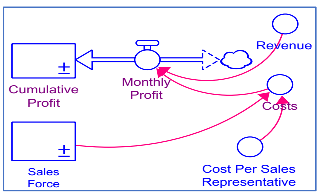


Figure 3.25: SFD calculating the Profit

Slide 19 in the ILE (Story 2 V&IV) allows for the learner to experience this trade-off by modifying the Sales Force Exogenously, to observe the counteracting response in the Sales Force and the Sales Effectiveness as well as the resulting Monthly Profit, reaching a maximum as the Sales Force passes 276, corresponding to a Sales Effectiveness of 5.4. This is scaffolding set the learner up for an in-depth analysis of this second trade-off.

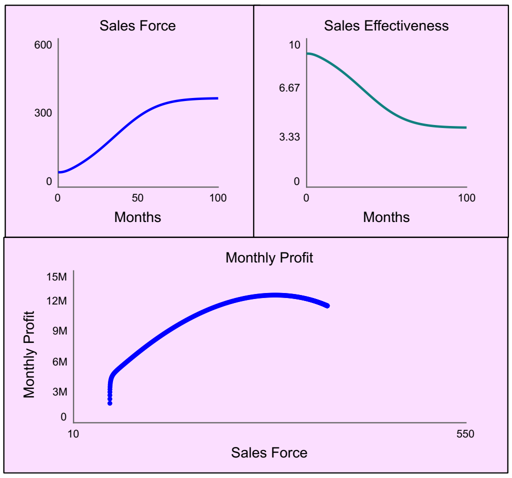


Figure 3.26: Sales Force with respect to the Monthly Profit

Slide 20 - 23 in the ILE (Story 2 V&IV) introduces the learner to the analytic optimization of the Sales Force with respect to the Monthly Profit:

To optimize the Sales Force with respect to the Monthly Profit Rate, recognize that;

Monthly Profit = Revenue - Costs

=

Reported Revenues

-

Costs pr Sales Representative * Sales Force

=

Price * Sales Effectiveness * Sales Force

–

Costs pr Sales Representative * Sales Force

As we may substitute Sales Effectiveness with;

Ref Sales Effectiveness *

(1- Ref Sales Effectiveness * Sales Force / Market Sales Potential),

assuming that an equilibrium may be found when

Reference Sales Potential / Market Sales Potential < 1),

then company profit is;

Price * Ref Sales Effectiveness

* (1- Ref Sales Effectiveness * Sales Force / Market Sales Potential) * Sales Force

–

Costs pr Sales Representative * Sales Force

=

Price * Ref Sales Effectiveness

* (1- Ref Sales Effectiveness * Sales Force / Market Sales Potential) * Sales Force

–

Costs pr Sales Representative * Sales Force

=

Price * Ref Sales Effectiveness * Sales Force

–

Price *Ref Sales Effectiveness ^{2} * Sales Force ^{2} / Market Sales Potential

–

Costs pr Sales Representative * Sales Force

Taking the derivative of this expression with respect to Sales Force yields;

Price * Ref Sales Effectiveness

–

Price * Ref Sales Effectiveness ^{2} * 2 * Sales Force / Market Sales Potential

–

Costs Per Sales Representative

With

Price * Ref Sales Effectiveness

–

Price * Ref Sales Effectiveness ^{2} * 2 * Sales Force*Market Sales Potential

–

Costs pr Sales Representative

The first order condition for optimum is setting this expression equal to 0,
and we may then solve for the optimal Sales Force:

Sales Force

=

(Price * Ref Sales Effectiveness - Costs pr Sales Representative)

/ 2 * (Price * Ref Sales Effectiveness ^{2} / Market Sales Potential)

=

(1- Costs pr Sales Representative / (Price * Ref Sales Effectiveness))

* Market Sales Potential / (2* Ref Sales Effectiveness)

Slide 23 of the ILE (Story 2 V&VI) introduces the learner to a numerical example demonstrating that the optimal Fraction Of Revenue To Sales is not 0.2, - i.e. the standard value applied thus far, - rather 0.148148:

With
- Costs pr Sales Representative = 6000
- Price = 10000
- Reference Sales Effectiveness = 10;
- Market Sales Potential = 8000,

then, indeed, the
Optimal Sales Force = 276
The result confirms the experimental findings of the learner obtained in Slide 19.

Moreover Sales Force = 276 implies that Sales Effectiveness = 5.4 and that
Backlog = 2 980,80, so that the Monthly profit = 12.7 M.

The implication is that the optimal Fraction of Revenue To Sales is not 0,2, that what we have worked with so far and that is sub-optimal, but;

Optimal Fraction Revenues To Sales

=

Optimal Sales Budget / Reported Revenue

=

(Optimal Sales Force * Cost Per Sales Representative)

/

(Optimal Sales Force * Optimal Sales Effectiveness * Price)

=

Cost Per Sales Representative / (Optimal Sales Effectiveness * Price)

=

8000 / (10 000 * 5.4)

=

0.148148

Slide 25 in the ILE (Story 2 V&VI) allows the learner to confirm that a Fraction of Revenue To Sales of 0.148148 indeed does produce the optimal equilibrium condition, possibly after a transition, characterized by a Sales Force of 276 and a Sales Effectiveness of 5.4.

Moreover Slide 25 in the ILE (Story 2 V&VI) allows the learner to, experimentally, set the model in that optimal equilibrium condition and to study various transitions towards that equilibrium by controlling the Sales Force.

3.3.4.2 *The Monthly Profit after Optimization in the Limited Market*

When we compare our results with the steady state found in 2 III, there the steady state gain was calculated by the amount of Budget allocated as the 20 percent of the total Revenue to manage the Sales Force. We got different amount of profit gained with different Fraction Revenue to Sales. There is an important pattern showed by the graph below. In each case there was a highest point which reduced to the steady state. The highest point is getting normalized with the increased Fraction Revenue to Sales and finally there was no any overshoot left.

Figure 3.27: Monthly Profit with different Fraction Revenue to Sales

That gave the idea of getting highest amount of profit could be achieved if we could manage to get an optimal point for the Fraction Revenue to Sales. For that the Optimal Sales Force was calculated and hence the Optimal Fraction Revenue to Sales. Following graphs shows the difference in Monthly Profit before and after introduction optimization in the system. There is a point of overshoot in previous condition but after introduction of optimization, once the Monthly Profit gets its height it remains at steady state to the end. Red line is Monthly Profit with Market Sales Potential 8000 and blue line is with 6000.

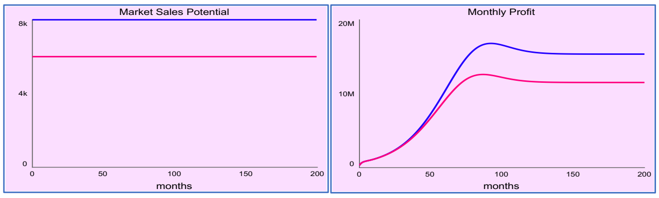


Figure 3.28: Market Sales Potential and Monthly Profit

In the case of Market Sales Potential 6000, the Monthly profit grow exponentially and became highest, 12.6 million at the month of 83 and then slightly decreased and become steady at 11.5 from the month of 134. In the case of Market Sales Potential 8000, the Monthly profit grow exponentially and became highest, 16.8 million at the month of 89 and then slightly decreased and become steady at 15.4 from the month of 132.

Monthly Profit given by different Fraction Revenue to Sales before optimization has been taken with the Backlog initiated at 80. Initially there was an exponential growth because of the reinforcing loop R1 dominating the basic market growth system even though there are other local balancing loops (B1, B2 and B3), they play very little influence. After some months the system gets into the steady state. So, steady state condition in 2 III is suboptimal. There is possibility of getting greater profitability with lower allocation of Revenue to Sales i.e. the policy allocated 20% of revenue to Sales Force is sub-optimal. Now, the calculated Optimal Fraction Revenue to Sales works instead of Fraction Revenue to Sales and brings the system in optimum level.

Market Potential is not only variable that lead to higher profitability in the system. By taking different values of price, cost, and fraction revenue we can attain different behaviours in profitability. For example, we can try the following conditions with Market potential =6000 and 8000 correspondingly and find out the maximum profitability. Are they maximum?

1. Price =10000, Cost = 8000, Fraction Revenue=0.15, Profit=12.7M and 16.9M
2. Price =12000, Cost = 8000, Fraction Revenue=0.2, Profit=12.8M and 17.1M
3. Price =10000, Cost = 10000, Fraction Revenue=0.2, Profit=12M and 16M
4. Price =8000, Cost = 6000, Fraction Revenue=0.25, Profit=7.56M and 10.1M

Maximum profitability can be seen in condition 2 in which monthly profit reached to 15.5M and stabilize at 12.8M with market potential 6000 and 17.9M and stabilize at 17.1M with market potential 8000. That means, Sales Force is the main factor where we could do something to get the optimal profit as;

Optimal Monthly Profit

=

*(Total Sales * Price) – (Optimal Sales Force * Costs per Sales Representative)*

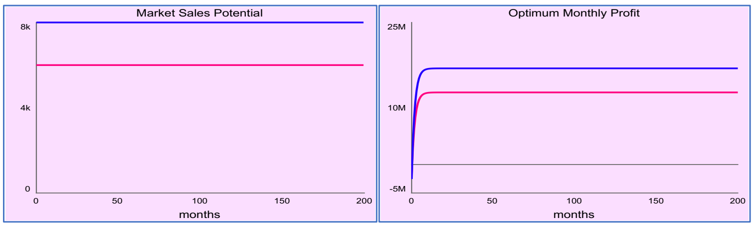


Figure 3.29: Market Sales Potential and Monthly Profit

3.3.4.3 *Initialization of the Model in an Optimum Steady State*

The main problem associated with the market is Backlog management. To initialize the model in an optimum steady state, we first need to initialize the Backlog at its Optimum value i.e. Backlog with the calculated Optimal Sales Force. Reference Sales Effectiveness and Market Sales Effectiveness are also included here so as to find the Optimal Initial Backlog. Here we have an equation for initializing our Backlog at its optimal level as;

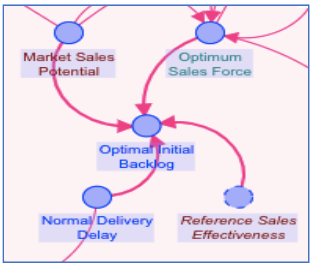


Figure 3.30: Optimal Initial Backlog

Optimal Initial Backlog

=

Optimum Sales Force

* Reference Sales Effectiveness

*MAX (1-Optimum Sales Force *

Reference Sales Effectiveness / Market Sales Potential, 0)

*Normal Delivery Delay

Earlier in this task the Backlog is initiated at 80 batches. After the calculation of Optimal Initial Backlog as mentioned we get the following behaviour graph;

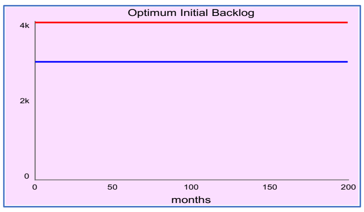


Figure 3.31: Optimal Initial Backlog

The difference in Optimal Initial Backlog can be seen by changing the value of Market Sales Potential. System gets 3.97k batches of Optimal Initial Backlog with 8000 Market Sales Potential and 2.98k Optimal Initial Backlog with 6000 Market Sales Potential. The Backlog is initiated at 80.

This optimization is only used to find out the values of various variables so as to get the Optimal Profit for the company. Here, there are not many differences in the behaviour produced by the system in comparison to the previous sections. We just compare the normal values and the optimal values for the different variables with their corresponding simulation behaviours when the system is at steady state condition.

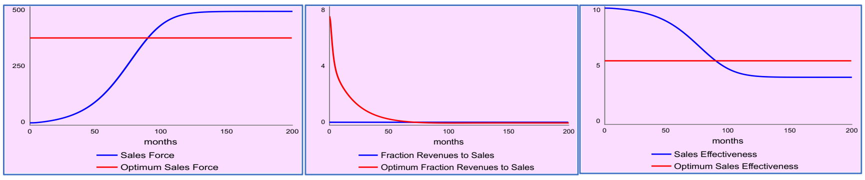


Figure 3.32: Exponential growth smoothed by the loop B4

These graphs are showing Sales Force and Sales Effectiveness in the saturated market condition and after the introduction of optimization condition. In saturated condition those two variables are at steady state condition. After optimization, they are showing the exponential growth and decay at the earlier which finally gets to the steady state. In the case of Fraction Revenue to Sales the condition is opposite. The values of Sales force, Fraction Revenue to Sales and Sales effectiveness are 480, 0.2 and 4 whereas they are 368, 0.148 and 5.4 after optimization. There is no difference for Fraction Revenue to Sales and Sales effectiveness with 8000 as Market Sales Potential but the Sales Force is 360 before and 276 after the optimization with 6000 as Market Sales Potential.

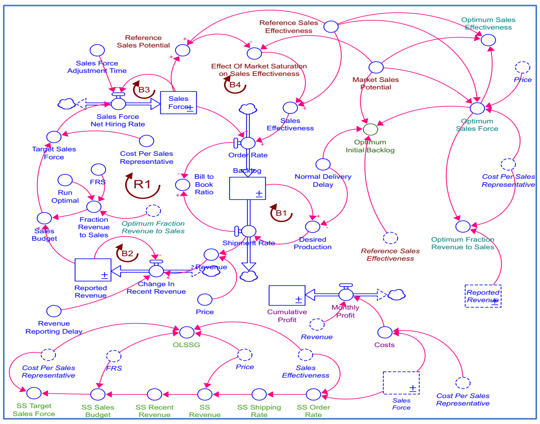


Figure 3.33: Optimized Market Growth Model

3.4 Limited Capacity and its Utilization

So far, we have assumed that there is enough Shipment Capacity to satisfy demand (Desired Shipment). The Desired Shipment is equal to the Backlog shipped with the Normal Delivery Time. But there are certain constraints which limit the Shipment Capacity in real market situation. For that Shipment Capacity Constraint, we are incorporating the Capacity Utilization while defining the Shipment Rate. The Normal Delivery Delay is now considered to be the Company Goal for Delivery Delay which is 2 months. That means the Desired Shipment Rate is now the ratio between Backlog and the Company Goal for Delivery Delay.

Shipment Rate = Desired Shipment Rate

=

Backlog / Company Goal for Delivery Delay

3.4.1 *Limited Shipment Capacity*

In fact, however, the company is characterized by a limited Shipment Capacity. So, the Shipment Rate depends on the Current Capacity and may differ from Desired Shipments. Whatever Capacity is currently available, is utilized to the extent desired. The ratio that represents the Desired Capacity Utilization is the actual Capacity Utilization i.e.

Capacity Utilization

=

Desired Shipment Rate / Current Capacity

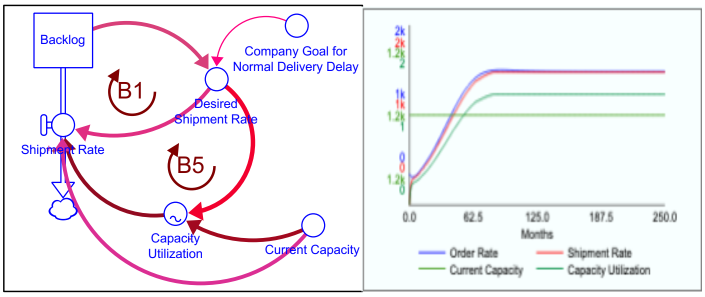


Figure 3.34: Limited Shipment Capacity

At this point we can change the value of Current Capacity and see the difference in model behaviour as shown in above figure (3.52), the behaviour shown by putting the value of current Capacity at 1200. The Current Capacity at the same time also has direct effect on the Shipment Rate as;

Shipment Rate

=

Current Capacity*Capacity Utilization

The Balancing Loop B1, now takes on a somewhat different role. The Shipment Rate no longer unconditionally takes the desired value but is conditioned upon the Current Capacity. Thus, the strength of Loop B1 is conditioned by that capacity.

Whatever the capacity available at any point in time, get utilized only to some extent. It explains the percentage utilization of Current Capacity required determining the Desired Shipment Rate and the actual amount of the orders get shipped. Such Capacity Utilization is given as the graphical function of the ratio between demand (Desired Shipment) and supply (Current Capacity) as given below:

Capacity Utilization

=

GRAPH (Desired Shipment Rate / Current Capacity)

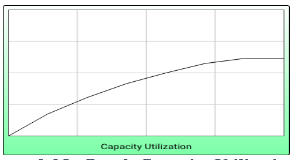


Figure 3.35: Graph Capacity Utilization

The higher ratio means the greater utilization of the Current Capacity to satisfy demand. Capacity Utilization is represented in the model as the graph function and introduces another feedback loop B5 and replaces earlier balancing loop B1. This balancing loop B5 regulates the system with the concept of limited capacity. The Capacity Utilization works as follows:

As long as there is ample capacity, i.e.;

Desired Shipment Rate / Current Capacity < 1

The Capacity is utilized to a fuller extent then strictly necessary as there are Orders in the Backlog. Thus, a smaller portion of the Current Capacity is being wasted and there is shorter delivery time. When there is a capacity shortage, i.e.;

Desired Shipment Rate / Current Capacity > 1

The Capacity is being over-utilized in an attempt for the Shipment Rate to meet the Desired Shipment Rate. As not being fully successful, the over-utilization goes some way in bringing the Delivery Delay towards the Company Goal for Delivery Delay.

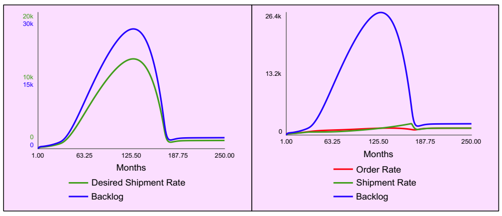


Figure 3.36: Capacity Utilization

Current Capacity at the same time also has direct effect on the Shipment Rate as the Capacity Utilization part as:

Shipment Rate

=

Current Capacity*Capacity Utilization

+ Desired Shipment Rate * (1-Switch for Capacity Constraint)

Since we are using more than one variable individually affected the Shipment Rate and it gives the different results in each condition, we need to use a switch for differentiating all the effects. Switch shows the system either uses the Desired Shipment or the Capacity Utilization out of the Current Capacity. That means if there is no Capacity Constraint then all the Desired Shipment Rate gets fulfilled but in the case of Capacity Constraint then the Shipment Rate is calculated by Capacity Utilization with Desired Shipment Rate and hence the process of shipping follows the other way. Fig. 3.55 shows the difference between behaviour produced by Shipment and Desired Shipment Rates.

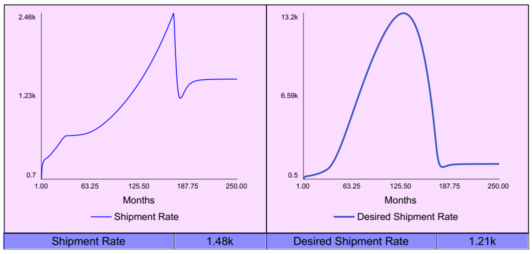


Figure 3.37: Capacity Utilization and Shipment Rate

Current Capacity is, in fact, dynamic and acquired by the company in response to the need for the capacity (Desired Capacity) by each company. The adjustment of capacity through planning and acquisition or discards follows a third order 3 months delay. The average time it takes to establish / discard capacity may vary from company to company, - each conditioning the extent to which Loop B1, and thus the Shipment Rate is being conditioned.

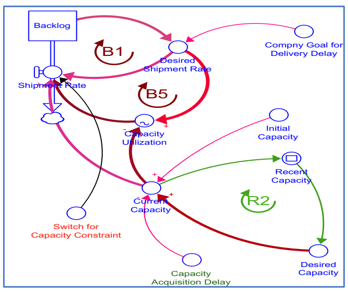


Figure 3.38: Current Capacity

Current Capacity

=

DELAYN (Desired Capacity, Capacity Acquisition Delay,3, Initial Capacity)

Initial Capacity and Capacity Acquisition Delay are parameters and their values are set as *1000 and 72 respectively.*

Current Capacity on the other hand gives the Recent Capacity which ultimately plays an important role to define the Desired Capacity after some time. The Recent Capacity in short term is the average of the Current Capacity. Recent Capacity is nothing but the delayed Current Capacity. So, it is expressed as;

Recent Capacity

=

(SMTH1(Current Capacity, 0.5))

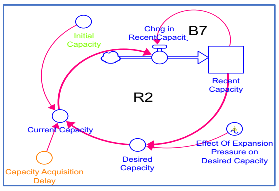


Figure 3.39: Recent Capacity

3.4.2 Desired Capacity

The Desired Capacity is determined by the Recent Capacity, boosted by the Effect of a Pressure to Expand (or Contract) Capacity. This Effect of Expansion Pressure on Desired Capacity is expressed as the fractional change in Desired Capacity, - relative to the most Recent Capacity:

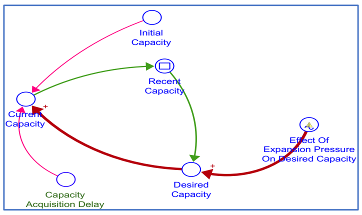


Figure 3.40: Desired Capacity

Desired Capacity

=

*Recent Capacity*Effect of Expansion Pressure on Desired Capacity*

The Effect of Expansion Pressure on Desired Capacity is given by the following graphical function and the values for Pressure to Expand Capacity and Effect of Pressure to Expand Capacity are given as in the table below.

Pressure to Expand Capacity	Effect of Pressure to Expand Capacity
0.000	0.300
0.500	0.750
0.100	1.000
1.500	1.200
2.000	1.400
2.500	1.600
3.000	1.800
3.500	2.000
4.000	2.100
4.500	2.170
5.000	2.200

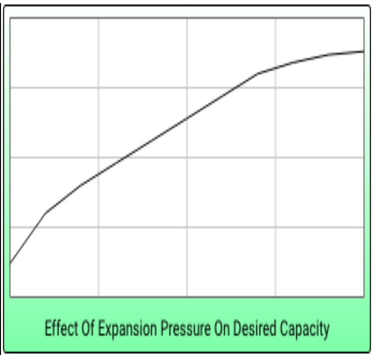


Figure 3.41: Graph Effect of Expansion Pressure on Desired Capacity

The effect responds to the pressure in a way described as in the graph function below;

Effect of Expansion Pressure on Desired Capacity

=

GRAPH (Pressure to Expand Capacity)

The greater the pressure, the larger will be the effect: Note that the marginal effect diminishes with an increase in the pressure; thus, say, a 500 % Pressure to Expand Capacity, merely materializes in a plan to expand by 220%. The Pressure to Expand Capacity originates from the Delivery Delay Perceived by the Company. This Perceived Delivery Delay is compared to the Company Goal for Delivery Delay (2 months, - a goal set by all the competitors). If the deliveries are not on time, then there is a Pressure to Expand Capacity as;

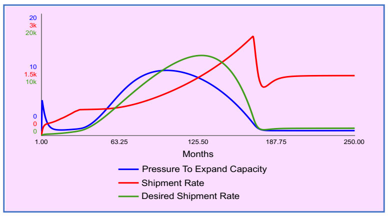


Figure 3.42: Pressure to Expand Capacity

Pressure to Expand Capacity

=

Delivery Delay Perceived by the Company

/Company Goal for Delivery Delay

The Company Goal for Delivery Delay thus serves two purposes- first; it determined the Desired Shipment Rate (gives the Backlog). It does so without a Delay. And the second, it contributes to define the Pressure to Expand (or contract) the Capacity to Shipment. This pressure causes, after a significant Capacity Acquisition Delay, the Current Capacity to meet the demand for Capacity and thus the Shipment Rate to adjust the Desired Shipment Rate (Fig. 3.59).

3.4.3 Actual Delivery Delay and Delay perceived by the Company

Delivery Delay Perceived by the Company compares with the (actual) Delivery Delay and measures against the Company Goal for Normal Delivery Delay as:

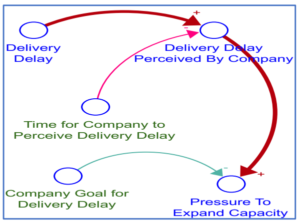


Figure 3.43: Delivery Delay

Delivery Delay Perceived by Company

=

SMTH1 (Delivery Delay, Time for Company to Perceive Delivery Delay)

The Delivery Delay is defined as the ratio between the Backlog and the short-term average (i.e. Recent) Shipment Rate,

Delivery Delay

=

Backlog / Recent Shipment Rate

The information about shipments is not immediately available and must be compiled, verified, and reported, - a process that takes 2 weeks (half a month). Consequently,

Recent Shipment Rate

=

SMTH 1 (Shipment Rate, 0.5)

Not only the capacity Acquisition Delay but also the tie for the Company to perceive the Delivery Delay plays an important role in the Capacity Sector. The real Delivery Delay as calculated above must be verified, confirmed, reported, acknowledged and trusted before it can form the basis for such significant actions as capital investments or divestments (Fig. 3.61)

The Delivery Delay expresses how long, on the average, the Orders remain in the Backlog until their execution is complete and Shipments can take place. Thus, the average Delivery Delay is the Backlog divided by the (short term) average (i.e. Recent) Shipment Rate as;

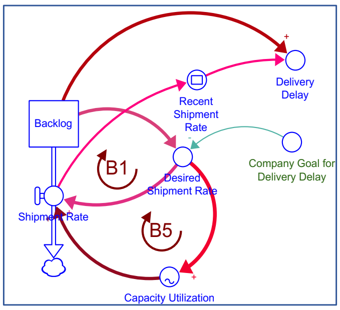


Figure 3.44: Delivery Delay and Shipment

Delivery Delay

=

Backlog / Recent Shipment Rate

Where,

Recent Shipment Rate

=

SMTH1 (Shipment Rate 0.5)

Delivery Delay Perceived by the Company compares with the actual Delivery Delay and measures against the Company Goal for Normal Delivery Delay (Fig. 3.60).

The information about shipments is not immediately available and has to be compiled and registered. It takes 2 weeks (half a month) to do so. For this we create an explicit first order information delay structure to cater for such a process to produce a "recent shipment rate".

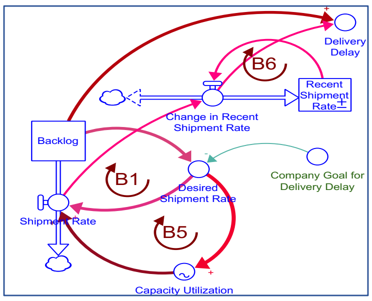


Figure 3.45: Change in Shipment Rate

Change in Recent Shipment Rate

=

(Shipment Rate - Recent Shipment Rate) / 0.5

Where,

Recent Shipment Rate

=

SMTH 1 (Shipment Rate, 0.5)

The Behaviour of the model may now be portrayed by comparing the Order Rate with the Desired Shipment Rate, the Current Capacity and the (actual) Shipment Rate. Figure 3.63 shows that current capacity following other variable till 187 months. After that period current capacity exceed order rate and shipment rate. All variable produces goal seeking behaviour to some extent.

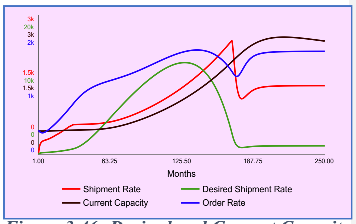


Figure 3.46: Desired and Current Capacity

3.4.4 *Balancing the Capacity Sector*

After completion of additional capacity sector in the model, three local balancing loops B5, B6 and B7 and two major balancing loops B8 and B9 appear in the system. B6 and B7 are the local balancing loops and hidden in the Recent Shipment Rate and Recent Capacity (Fig. 3.62 and 3.57) as they are taken as the delay converters. The two major balancing loops B8 and B9 appear simultaneously (Fig. 3.64). The triplets of negative loops B5, B8 and B9 serve the purpose of aligning the Shipment Rate with the Order Rate in the context of limited Capacity. They contribute to this alignment in three different ways.

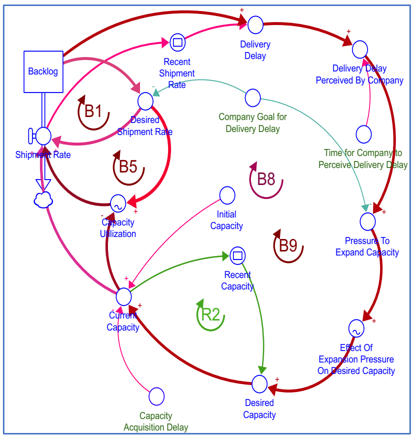


Figure 3.47: Balancing Capacity B5, B8 and B9

B8 is a major negative feedback loop and regulates the Backlog conditioned by the current Backlog and Shipment Rate. The regulation takes place with a delay by means of Shipment Capacity and eventually the Shipment Rate. The delay now is Company Goal for Delivery Delay, i.e. to make sure a Backlog level is produced and maintained so that the incoming Orders remain in the Backlog precisely with the time set by the Company Goal for Delivery Delay. When the Backlog is too large (so that the Delivery Delay is larger than the Company Goal for Delivery Delay), a Pressure to Expand Shipment Capacity is produced so as to drain the Backlog. In the reverse case, there is a pressure to reduce that Capacity so as to retain more Orders in the Backlog. In both cases, this requirement implies that the Shipment Rate has aimed to match the Order Rate. Delivery Delay, a Pressure to Expand Shipment Capacity is produced so as to drain the Backlog. Rate has aimed to match the Order Rate.

B9 is another feedback loop that regulates the Shipment Rate conditioned by the current Backlog and Shipment Rate. The regulation takes place with a delay by means of the Shipment Capacity. B9 complements B8. The goal for that regulation is, again, the Company Goal for Delivery Delay- i.e. to make sure a Shipment Rate is in place that, given the current Backlog level, causes the incoming Orders to remain in the Backlog for precisely the time set by the Company Goal for Delivery Delay when the Shipment Rate is too small (so that the Delivery Delay is larger than the Company Goal for such Delay), a Pressure to Expand Shipment Capacity is produced so as to reduce the Delivery Delay. In the reverse case, there is a pressure to reduce that capacity. In both cases, this requirement implies that the shipment Rate has aimed to match the Order Rate.

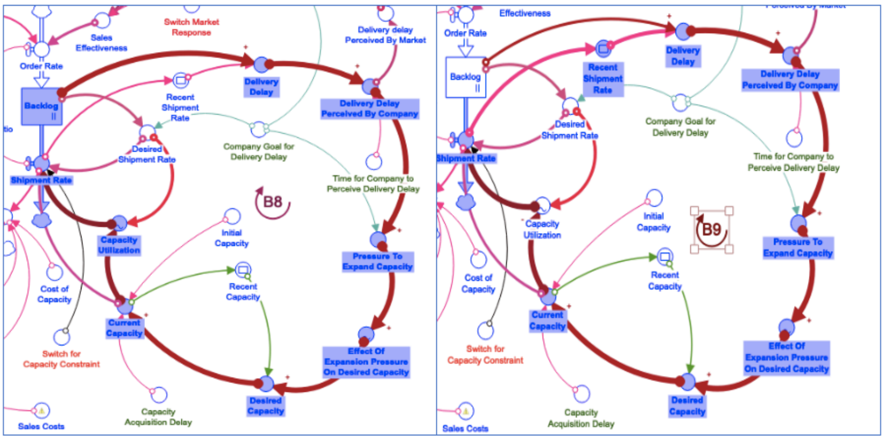


Figure 3.48: Balancing Capacity B8 and B9

B8 and B9 are having most part similar except the condition of Backlog and Shipment Rate. When the Shipment Rate is kept constant (through fixed Shipment Capacity), the Backlog level increases (or decreases), B8 creates pressure to change the Shipment Capacity. If the Backlog kept constant (through an adjustment of Order Rate), the Shipment Rate increased (or decreased). B9 is the loop that produces a pressure to change the Shipment Capacity. B8 and B9 have greater influences on the system because they are designed by three important level variables i.e. Backlog, Recent Capacity and Recent Shipment Rate. Higher Backlog forces the Capacity to expand so as to fulfil market demand. Once demand is fulfilled Backlog goes down and need less Capacity Utilization.

In order to distinguish B8 and B9, let us first assume that the Shipment Rate is kept constant (say through a fixed Shipment Capacity). In that case, if the Backlog level increases (or Decreases), B8 creates a pressure to change the Shipment Capacity. Let us then assume that the Backlog is kept constant through an adjustment of the Order Rate. In that case, if the Shipment Rate increases (or decreases), B9 is the loop that produces a pressure to change the Shipment Capacity.

The loop B5 is Short-circuiting (minor) negative feedback loop, - a loop that exercises a first order control (i.e. without a delay). It regulates the Shipment Rate in the short run, ´within´ the existing Shipment Capacity constraints by the way of the Capacity Utilization. Its primary task is to reduce, if called for the Capacity Utilization below 1. This happens when Desired Shipment Rate is below the Current Shipment Capacity. It brings the utilization somewhat above 1 in response to the pressure produced by the Desired Shipment Rate. The sort-circuiting role of B5 may be considered a way to dampen the effects of longer-term pressures while B8/B9 addresses the long-term (sustained) pressures that are not adequately addressed by B5 in the short run. When an adequate Capacity has been established, the responsibility for the adjustments is thus shifted back to B8/B9.

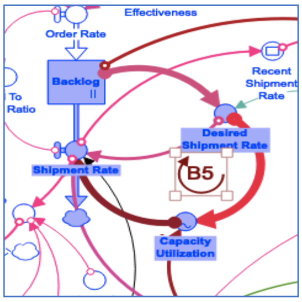


Figure 3.49: Balancing Capacity B5

3.4.5 The Second Major Reinforcing Loop

In addition to the balancing loops B5, B8 and B9, at the same time, the system gets one additional reinforcing loop when the Current Capacity directly joins to the Shipment Rate. If the Current Capacity is used without having any limitations, then there is the presence of this new reinforcing loop R3. This is the same condition as in the basic reinforcing loop R1 that means having no capacity constraint. In this situation the concept of Desired Shipment Rate is not needed to be considered because the Delivery Delay is calculated directly by the Backlog and the Shipment Rate. This major reinforcing loop R3, now includes the basic market growth sector with the capacity sector and replaces the previous major reinforcing loop R1(Fig. 4.67). Similarly, there is one local reinforcing loop R2(Fig. 4.67), which explains how the higher Current Capacity reinforces the further expansion of Current Capacity.

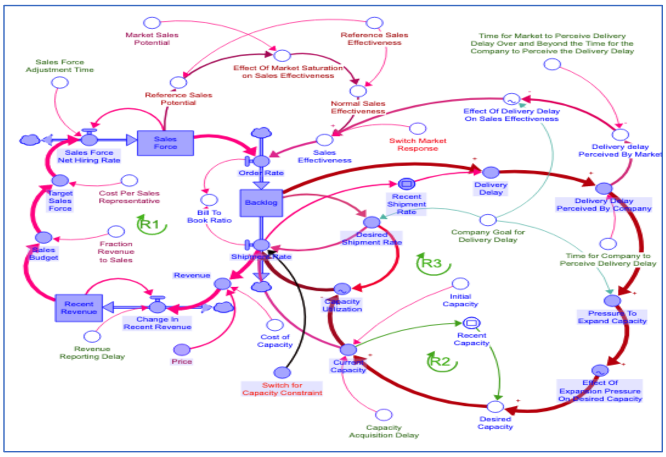


Figure 3,50: Reinforcing Loop R3

3.4.6 Influential factors for the Capacity

Sales Force is mainly dominated by R1 and B4. Exponential growth, goal seeking and steady state behaviour in Sales Force indicate the loop dominance to that point of time. Backlog shows reinforcing, overshoot and steady state behaviours. Balancing loop B8 has greater influence on defining Backlog. S-shaped growth in Current Capacity indicates the exact timing of the loop dominance in the system. The point in which the Shipment Rate exceeds the Order Rate explains that the company is able to extend capacity so as to clear Order accumulated in Backlog. Higher Delivery Delay perceived by company creates greater Pressure to Expand Capacity.

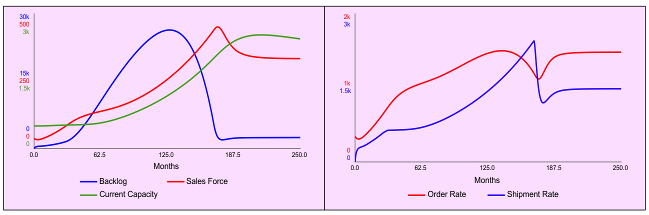


Figure 3.51: Sales Force dominated by R1 and B4

The major influencing factors of the system after including the limited Capacity part are Reference Sales Effectiveness and Capacity Acquisition Delay. These are major factors in the sense; we can influence directly to make the difference in the system. How they affect the system can be seen after the simulation with their different values correspondingly. The combinations might be:

Case	Reference Sales Effectiveness	Capital Acquisition Delay
1	10	72
2	10	36
3	15	72
4	15	36

Table 2: Cases (different value of variables)

Case 1: Reference Sales Effectiveness = 10, Capital Acquisition Delay =72.

When the Reference Sales Effectiveness is 10 and Capital Acquisition Delay is 72. The Desired Capacity is determined by the Recent Capacity (the Current Capacity smoothed by 2 weeks) and (is boosted by) the effect of a Pressure to Expand (or contract) Capacity. This pressure originates from the perception of whether the company is able to deliver on time (within 2 months, - a goal set by all the competitors) or not. The fig. 3.69 shows oscillation in delivery delay and effect of expansion pressure on desired capacity and linear growth in current capacity.

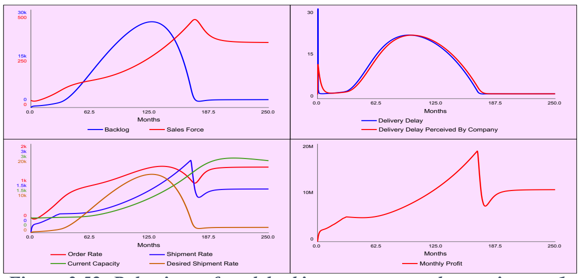


Figure 3.52: Behaviour of model taking parameter values as in case 1

As discussed earlier balancing loop (B8) has greater influence on the system because it is designed by three important level variables i.e. Backlog, Recent Capacity and Recent Shipment Rate. Higher Backlog forces the capacity to expand so as to fulfil the market demand. Once demand is fulfilled Backlog goes down and need less Capacity Utilization. Figure 3.70 above shows goal seeking, overshoot and collapse, exponential growth behaviour for different variables and explains that due to less time required to acquire capital, the system stabilizes at earlier stage. Shipment, Order Rate and Current Capacity are almost same at steady state condition.

Case 2: Reference Sales Effectiveness = 10, Capital Acquisition Delay =36

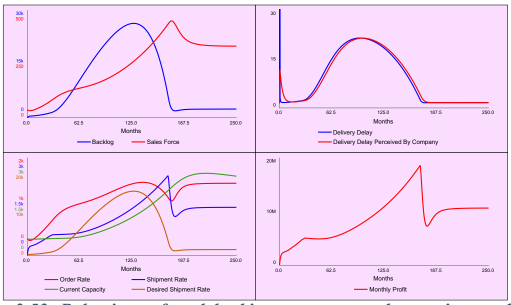


Figure 3.53: Behaviour of model taking parameter values as in case 2

Case 3: Reference Sales Effectiveness = 15, Capital Acquisition Delay =72.

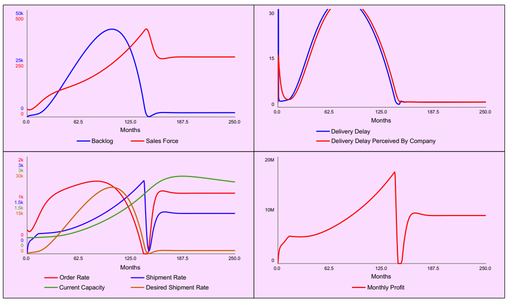


Figure 3.54: Behaviour of model taking parameter values as in case 3

. Case 4: Reference Sales Effectiveness = 15, Capital Acquisition Delay =36.

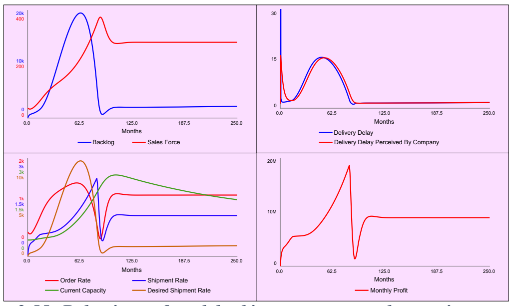


Figure 3.55: Behaviour of model taking parameter values as in case 4

With the existing value of Price, Cost and Fraction Revenue to Sales, the system reaches to an equilibrium state with the Sales Effectiveness 4. When Reference Sales Effectiveness increases to 15, the Sales Effectiveness becomes greater than 4 at its initial stage and later, due the domination of balancing loop B4, finally it reached at 4. The Sales Effectiveness greater than 4 accelerates the system. So, the behaviour shown in figure reveals the same behaviour as previous but in greater magnitude. In this situation steady state reaches at earlier point of time due to balancing loop B4 and B8 dominate the system that correct the system faster.

3.4.7 Additional Costs with Capacity Management

Cost associated with the capacity expansion has certainly affects the system. When capacity needs to expand, the revenue needs to divert to cover such cost that affects Sales Budget and Sales Force. This issue could be addressed by designing additional structure that defines the required Fraction of Revenue that covers the Cost. This structure thus certainly reduces the Revenue available for Sales Budget. In such situation the Optimal Steady State of the system will change. In new situation

Revenue
=
Shipment Rate*Price
-Shipment Rate * Price* Cost of Capacity

Simulating this feature Sales Force stabilized at 333 and Sales Effectiveness increased to 4.89 as shown in the figure below.

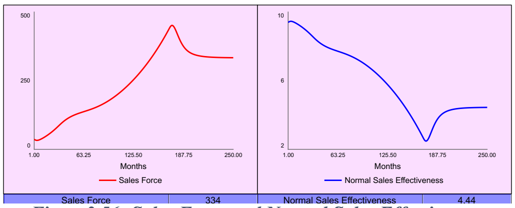


Figure3.56: Sales Force and Normal Sales Effectiveness

This structure reduces the revenue available for the Sales Budget. In such situation the optimal steady state of the system will change. For example, let us suppose that such cost is 10 percent of Reported Revenue, simulating this feature, the Sales Force stabilizes at 333 and the Sales Effectiveness increases to 4.45 as shown in the figure 4.73.

3.5 Effect of Delivery Delay on the Market Sector (task 4)

The model developed so far explains the behaviour produced by the basic market growth structure, market saturation and its effect on determining the Sales Effectiveness and company´s capacity to ship the desired amount of the product from the stock. Having concluded that the current model does not constitute the explanation for the dynamics portrayed in the reference mode given in the figure 1, we need to investigate further. This time we need to concentrate more on the Sales Effectiveness. It has not only been drifting, but with significant variations over time for each of the companies. The interviews with company clients show that the market is reacting negatively to unforeseen Delivery Delays. Therefore, it is necessary to investigate whether there is a relationship between the Delivery Delay and the Sales Effectiveness.

Introducing the Market Response to Delivery Delay

Now we make a market response switch on to see the effect of Delivery Delay in the Sales Effectiveness and finally in the system. The parameter values were taken same as in table 5 earlier. Sales Effectiveness is now determined by the Normal Sales Effectiveness and Effect of Delivery Delay on Sales Effectiveness. The resulting behaviour of sales force and Sales Effectiveness is shown as;

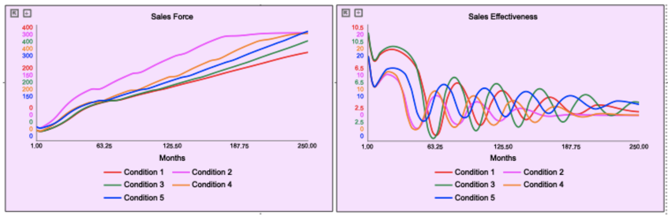


Figure 3.57: Sales Force and Sales Effectiveness with Market Response

While changing the parameter values, the simulated behaviour is similar as portrayed in the figure 1, but with the different values they generate.

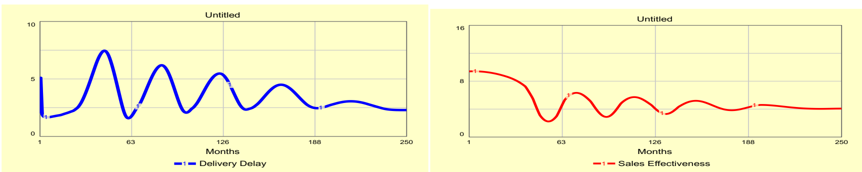


Figure3.58: Delivery Delay and Sales Effectiveness

Sales Effectiveness and Delivery Delay (in figure 4 in assignment in the case of Reference Sales Effectiveness -10 and Capital Acquisition Delay -72) show similar pattern of oscillations and stabilizations. The magnitude is different because of their different assumptions on Reference Sales Effectiveness and Capital Acquisition Delay. Due to the similar pattern of behaviour these variables produce, it can be concluded that there is relationship between these two variables, so we need to figure out the Delivery Delay and the Market´s Response to it. In addition, the only factor which alters the Shipment Capacity in extended market growth model is considered as the Delivery Delay. Now we search how such Delivery Delay affects the Sales Effectiveness of the company and finally modifies the overall dynamics of the system. Scaffolding of the additional part to reflect the effect of Delivery Delay on Sales Effectiveness is given below;

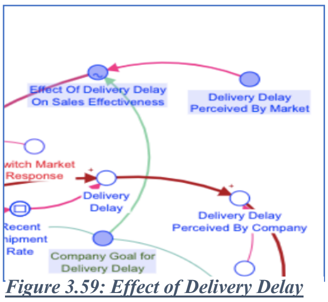


Figure 3.59: Effect of Delivery Delay

A new variable called Effect of Delivery Delay on Sales Effectiveness is introduced to the Sales Effectiveness (Fig 3.75). Sales Effectiveness can now be switched either to Normal Sales Effectiveness or to the Sales Effectiveness with the Effect of Delivery Delay on Sales Effectiveness as our need to see the effect of Delivery Delay on it or simply as the function of market saturation on Sales Force. This is the graphical function of Delivery Delay Perceived by Market and the Company Goal for Delivery Delay as;

Effect of Delivery Delay on Sales Effectiveness

=

GRAPH (Delivery delay Perceived by Market/Company Goal for Normal Delivery Delay)

Delivery Delay Perceived by Market is first order smooth function of Delivery Delay Perceived by Company and Time for Market to Perceive Delivery Delay Over and Beyond the Time for the Company to Perceive the Delivery Delay (Fig 4.73) and expressed as below;

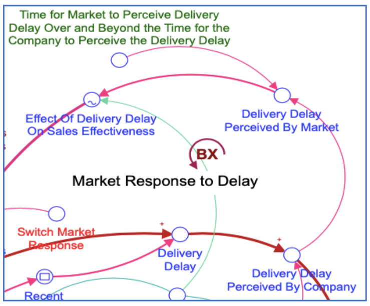


Figure 3.60: Market Response to Delay

Delivery Delay Perceived by Market

=

SMTH1(Delivery Delay Perceived by Company, Time for Market to Perceive Delivery Delay Over and Beyond the Time for the Company to Perceive the Delivery Delay)

Now we introduce the Effect of Delivery Delay on the market demand determined by the Sales Effectiveness. Market Response to Delivery Delay loop BX explains higher Delivery Delay Perceived by the Market lowers the Sales Effectiveness that further lowers the Order Rate. This loop causes oscillations in Order Rate. Now we see the effect of Delivery Delay in the Sales Effectiveness and finally in the system. The Sales Effectiveness is now determined by the Normal Sales Effectiveness and Effect of Delivery Delay on Sales Effectiveness as;

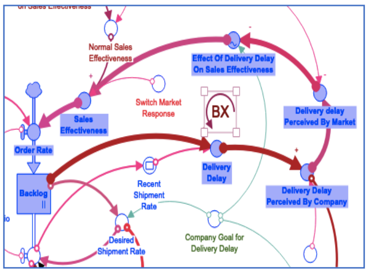


Figure 3.61: Effect of Delivery Delay on the Market Demand

Sales Effectiveness

=

Normal Sales Effectiveness*Effect of Delivery Delay on Sales Effectiveness

After introduction, we could capture the behaviour portrayed in figure 1 in the problem statement (Fig. 3.79). While changing the parameter values, the simulated behaviour is similar as portrayed in the figure 1, but with the different values they generate. The model, at this point, includes Sales Force Growth, Market Demand, Market Response to Delay and Capacity Expansion sector (figure 3.78).

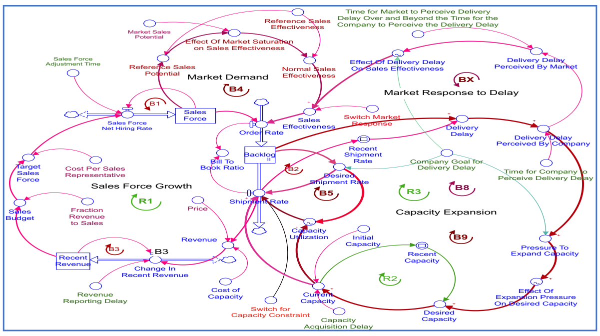


Figure 3.62: Extended Market Growth Model

Four different companies operating at similar Market Potential and other variables except Sales Effectiveness and Capital Acquisition Delay. Sales Effectiveness determines the Order Rate i.e. higher Sales Effectiveness generates higher Order Rate which accumulates at Backlog until the Demand Fulfilled through the Shipment Rate. Capital Acquisition Delay defines the time to establish Capacity to fulfil the additional Demand. That means higher Acquisition Delay creates the obstacles in Shipment Rate. Next, we describe the behaviour produced by this formulation considering 4 cases of the companies. Now we simulate and describe and interpret the outcome of the simulation noting that all companies operate with the same Market Sales Potential 6000 units per month, the same Fraction of Revenue 0.2 (20%), the same time for the company to recognize the Actual Delivery Delay. Moreover, all four companies start out from scratch with a Sales Force of 10 and a single Order in the Backlog, whilst Production Capacity is initially 500 units per month. The four different companies can be distinguished as in the following four cases.

Case 1: Reference Sales Effectiveness = 10, Capital Acquisition Delay = 72

In case 1, delay is greater than other case, so the companies meet their equilibrium state at the later stage. Such delays cause oscillations in the system.

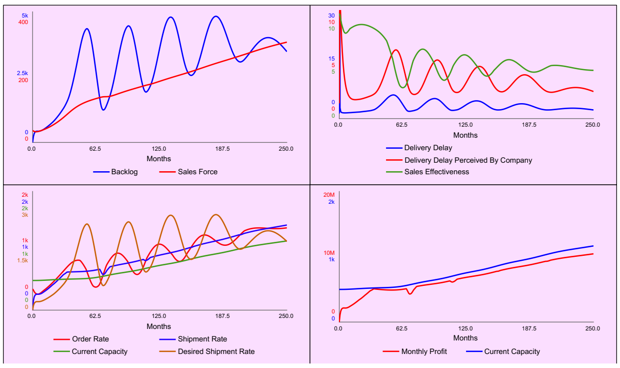


Figure 3.63: Case 1: Reference Sales Effectiveness = 10, Capital Acquisition Delay = 72

Lower Reference Sales Effectiveness here leads to lesser Sales Effectiveness leads to lesser orders generated. Backlog get emptied earlier which results lesser shipments and finally repetition of the cycles in lesser time causing more oscillations in the system. Due to higher Capital Acquisition Delay, the system reaches at equilibrium in later time period. Higher delay means the system is unable to build the capacity earlier that makes the delayed shipment to and more Backlog. Sales Force grows much more to handle the situation and it is harder to get the Steady State condition even at the last months.

Case 2: Reference Sales Effectiveness = 10, Capital Acquisition Delay = 36

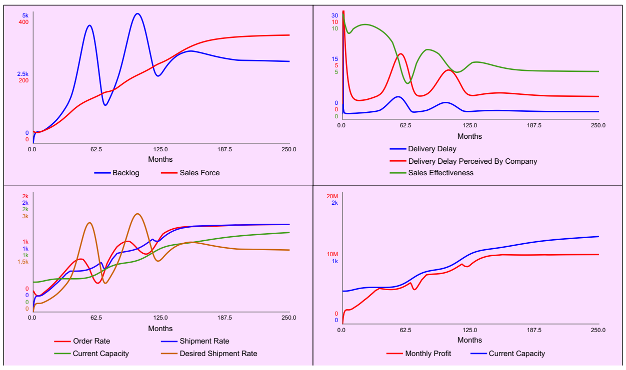


Figure 3.64: Case 2: Reference Sales Effectiveness = 10, Capital Acquisition Delay = 36

Due to lower Capital Acquisition Delay than earlier, the system reaches at equilibrium in earlier time period. Lower delay means there is the ability to enhance the capacity earlier that makes greater shipment to release the Backlog earlier. Sales Force grows almost to steady state. In this case system reaches at steady state even at earlier stage than in the previous cases due to the lower Acquisition Delay that fasten the Shipment Rate i.e. company is able to meet demand earlier.

Case 3: Reference Sales Effectiveness = 15, Capital Acquisition Delay = 72

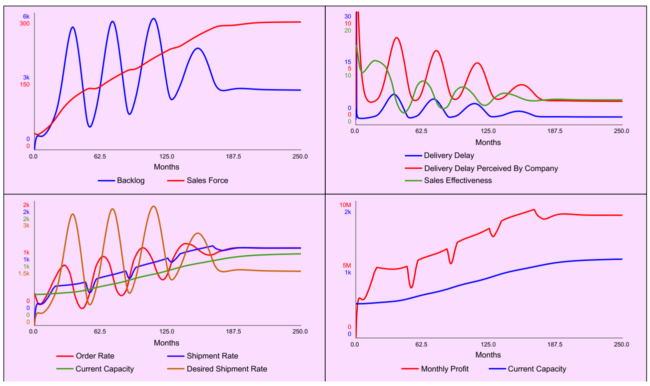


Figure 3.65: Case 3: Reference Sales Effectiveness = 15, Capital Acquisition Delay = 72

Increased Reference Sales Effectiveness here leads to greater Sales Effectiveness at initial stage giving higher Order Rate. Shipment could not follow to satisfy that higher Order Rate due to the higher Acquisition Delay which finally forces the Backlog to rise. Later, with the Market Perception of Delivery Delay, the Sales Effectiveness drops down. Higher oscillation in Delivery Delay is seen in case 3 because of greater Sales Effectiveness and higher Capital Acquisition Delay. Greater Sales Effectiveness increases Order Rate but at the same time capacity adjustment takes greater time so as to speed up shipment for reducing Delivery Delay.

Case 4: Reference Sales Effectiveness = 15, Capital Acquisition Delay = 36

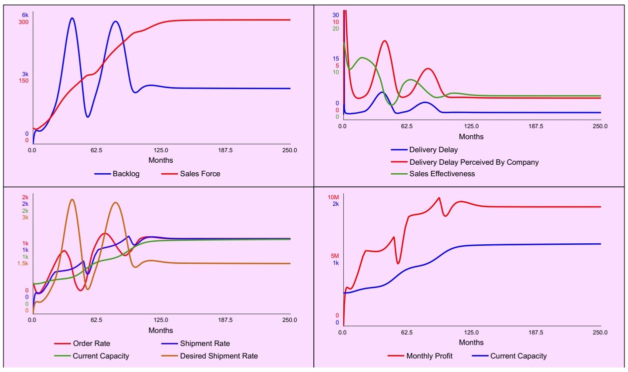


Figure 3.66: Case 4: Reference Sales Effectiveness = 15, Capital Acquisition Delay = 36

In case 4, system reached at steady state even at earlier stage than previous case due to the lower Acquisition Delay that foster the Shipment Rate i.e. company is able to meet demand earlier. Oscillation in Delivery Delay is higher in magnitude but stabilizes at earlier stage. This is because of higher Sales Effectiveness which forces to increase Order Rate and jump Delivery Delay, but at the same time due to low Capital Acquisition Delay the company is able to speed up the Shipment Rate so that the Delivery Delay could be reduced at earlier stage than in previous case.

The current model now explains the behaviour of the four companies portrayed in figure 1 in problem statement.

In task 2 and 3 we incorporate Sales Growth (loop R1), Market Demand (loop B4) and Capacity Expansion (loop B5, B8 and B9) in the system. In task 4 we have introduced the market response to the system. Reinforcing loop R1 tends to show exponential growth when it is strong, balancing loop B4 tends to control the Order Rate by adjusting Sales Effectiveness. This loop explains why greater Sales Force reduces the Sales Effectiveness. Loop B8 tends to manage Shipment Rate by adjusting Capacity. The overall model behaviour in terms of the behaviour mode arising from;

- adjusting the Sales Force in the medium term;
- expanding Capacity in the long term, and,
- a short run market mechanism whereby the Market Responds to Delivery Delay by influencing the Sales Effectiveness.

To see the model behaviour of different sector wise, we have used Switches for Capacity Constraint and Market Response. We can manage those switches as our need so as to see the behaviour of particular section of the model. For example, when we switch off both of these switches, the Shipment Rate is determined by desired Shipment Rate.

Expanding capacity in the long term

Now we make Switch for Capacity Constraint on to see the effect of capacity expansion loop in the system (Fig. 3.84). The parameter value is taken same as in table 5 presented earlier. Shipment Rate in this formulation is determined as

The resulting behaviour of Sales Force is shown as;

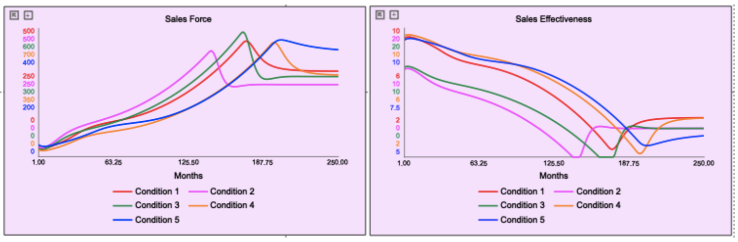


Figure 3.67: Sales Force and Sales Effectiveness without market response

Lower Sales Force is required when the Sales Effectiveness is higher. Capacity Acquisition takes time, so the Shipment Rate is lower at initial stage. When capacity extended to sufficient level then less Sales force is required. Overshoot and collapse behaviours in the Sales Force show, at point 200, there is the highest requirement of the Sales Force.

3.6 An Interplay between the Loops

Structure governing the Capacity Expansion (B8 and B9) and Market Response to Delay loop (BX) explains the dynamics of Capacity Development and Market Response to Delivery Delay.

Capacity Expansion loop is designed from two streams Backlog and Shipment generating balancing loop. This loop controls the Shipment Rate in the system. The magnitude of this loop is largely determined by Capacity Acquisition Delay. Market Response to Delay loop is designed from Backlog and control Order Rate by adjusting Sales Effectiveness. The effect of this loop will be greater when Market Perception of Delay is shorter period of time. There are others local balancing loops B6 and B7 affecting capacity expansion. Similarly, R2 also has an effect on Capacity Expansion.

Interplay between these two loops generates oscillating behaviour in Order Rate and Shipment Rate. Capacity Expansion governs Shipment and Market Response to Delay governs Order Rate. The Time to Acquire Capacity and Time to Market Perception of Delay has opposite influence on each other. Lower Market Perception affects Order Rate faster and lower Capacity Acquisition Delay affects the Shipment Rate.

3.7 Conclusion

This chapter has discussed about computer-based scaffolding to understand market growth model by Jay W. Forrester. The focus has been paid to design scaffolding using interface mode of Stella Architect software. One of the assignments from the GEO SD 303 course is taken as a case for creating ILE by the scaffolding. The attempt has been made to develop and describe the structure and behaviour of market growth model step by step.

Overall market growth model covers the production and the market sector. There are Sales Force growth, Order Fulfilment, Production Capacity and Customer Demand. In task 2 I, II, III, IV, V and VI we developed structure relating to Sales Force and Order Fulfilment with the assumptions that the production and customer demand has no restrictions. Sales Effectiveness determines customer´s Order Rate and Shipment Capacity with delay. Parameter values such as Price, Cost, Fraction Revenue to Sales, Reference Sales Effectiveness and delay components with level variables have remarkable effect on the behaviour produced after the simulation.

In task three we added capacity component in the model and the system behaviour with different values of various parameters. We examined Capacity Expansion Cost and its effect on Revenue available for the Sales Budget. In such situation we found the Optimal Steady State of the system has been changed.

In task 4 we added structure that consider Market Response to Delay. To this additional structure, there is balancing loop BX which works on Delivery Delay and Market Response to that Delay. This also adjusts Order Rate by adjusting Sales Effectiveness. The model developed in task four explains the behaviour of the four companies portrayed in figure 1 in the problem statement. This stage of market growth model explains why greater Sales Force reduces the Sales Effectiveness, controls Order Rate by adjusting Sales Effectiveness and manages the Shipment Rate by adjusting Capacity.

At last, attempts have been made to characterize the overall model behaviour in terms of the behaviour mode arising from the Sales Force adjustment in the medium term, Capacity Expansion in the long run and Market Response to the Delivery Delay by influencing the Sales Effectiveness. Finally, we explain the interplay between the loop governing the Capacity Development and the loop governing the Market Response to Delivery Delay.

The structure and behaviour associated with the market growth model are described above. We discussed how structure determines the behaviour and on the basis of produced behaviour one can find the way of modifications in the structural part. The feedback mechanism in the system makes sure how structure determines the behaviour. The state of feedback system is determined by its previous state and the change in that state over the subsequent period of time. How state variables develop over time and how changes in the state of a system vary depending upon the state of the system itself. State of a system often influences itself through a variety of feedback loops and that, in non-linear systems, the intensity of that feedback may vary so that different loops dominate the behaviour of the system over consecutive time intervals. In such systems, we may experience shifts in feedback loop dominance, often associated with dramatic behavioural consequences (Davidson, 2000). Graphical integration helps in understanding accumulating behavior in first-order open-loop systems (Phuah, 2010). In first-order linear systems, two basic rules give perfect predictions of behavior: reinforcing loops give rise to exponential growth, and linear counteracting loops give rise to exponential decay towards some goal. In higher-order linear systems the two rules are supplemented by a third basic rule stating that oscillations can occur. However, in higher-order systems, these basic rules no longer give perfect explanations of behavior (Davidson, 2000).

CHAPTER FOUR: TRANGIEN GAIN COMPONENT

4.1 Introduction

There is another way of looking at (Market Growth Model) MGM. For this a separate ILE has been developed where we can see how we use the growth concept in MGM. This SD modelling-based ILE is developed to understand complex dynamic systems. Stella Architect is being used to offer seamless transition between model on the one hand and simulation on the other. Modelling tool, simulation tool, interface design tool and story development tools all are integrated in the stella architect. The connection between model and simulation allows us to do the analysis and then when we build ILE, then we can create some pictures here to develop a tool called ILE. Here we are primarily concentrated on the analysis based on modelling and simulation and the dissemination the part of it the focus right now. Something that connect the simulated behaviour to the underlying structure.

For all ILEs we need to know how we should navigate and influence the ILE and how do we interact. In this case I am using arrows, run button, slider, nob and flight simulator. They are having their actions and, in each slide, there is the sequence of numbers to follows from 1 and above which helps to follow the sequence of actions in that slide. A red arrow is used to go to the next page, run button to run the model and an aeroplane is to make model in flight mode, sliders are to make the difference in values for the selected variable.

In this chapter we are talking about the MGM considering only the gain perspective. We are going to explain the gain in general. There are two ways to look at the modelling. The traditional way of looking at the simulation of the model where we see the behaviour of individual variables (Stocks, flows and other parameters) and their effect on each other. We describe the development over time and try to forecast the future planning as the solution of the problem the system is reflecting. Beside that there is a different concept traditionally introduced to the Market Growth Model that is Open Loop Steady State Gain (OLSSG). There we are supposed to get the concept of growth gained by the system in Steady State condition. OLSSG is calculated as the product of parameters influencing the system. If it is 1 the system is in equilibrium condition, when it is more than 1 the system has growth and when it is less than 1 the system is having decay. But there is a missing link where it was not shown that what makes it behave like that. There must be something which works with the Steady State Gain and gives the Total Gain of the system when the system is not in equilibrium position.

That new concept is given the name Transient Gain Component (TGC) which gives the Total Gain to the system when gets together with Steady State Gain as;

Steady State Gain*Transient Gain Component =Total Gain

This new term TGC is developed because of the delays in the system. When there is a delay from inflow to outflow, here in the case of Market Growth Model, time taken for Orders to be Shipped, Revenue to be adjusted as Recent Revenue and Sales Force following the Target Sales Force.
Sales Effectiveness along with Fraction Revenue to Sales and other parameters are responsible to make the system in Steady State condition. In the case of MGM, it is important to distinguish between the parameters in that loop and the Backlog. If we do not have Steady State and Sales Effectiveness is independent of the Sales Force as it is now, then we can choose whatever Backlog we want to have. As we know by previous tasks, Backlog does not define the steadiness of the state but the state itself so we need to choose something which will define the state of the system.

After the introduction of limited marked, when the system is at SSC, all the parameters have certain fixed value so if there is any change in one or more variable, it needs to have change in other variables so as to retain the steadiness. As we vary the value of these parameters, we can observe the resulting adjustment of the SE acquired to retain the model in Steady State.

Experimentation

Students can increase the Steady State Gain (SSG) and get the exponential growth or exponential decay by decreasing the value. All of the parameters give us the opportunity to go to equilibrium condition, to growth or to decay. Here we can make changes in Sales Effectiveness and Fraction Revenue to Sales and observe the values of the SSG and Total Gain. They have different values. In the case of SE 4.5, SSG is 1.13 whereas the total gain is only 1.1. If we do it more extensively say Sales Effectiveness is 5, SSG is now 1.25 while the total gain is only 1.19. This is because of the delay in the system primarily because of Normal Delivery Delay and Recent Revenue Adjustment Delay. We are looking at the Open Loop Steady State Gain (OLSSG) and Open Loop Total Gain in the system. Since it is the gain between Target Sales Force and Sales Force, we are not considering the delay between these two. The point is, this mechanism divides the difference between the Target Sales Force and Sales Force. The question here is where is this difference coming from? If there has been no delay between Order Rate and Shipment Rate and no delay in the Recent Revenues adjusted to the Revenues, then Total Gain would have been as same as the SSG i.e. 1.25 when Sales Effectiveness is 5.

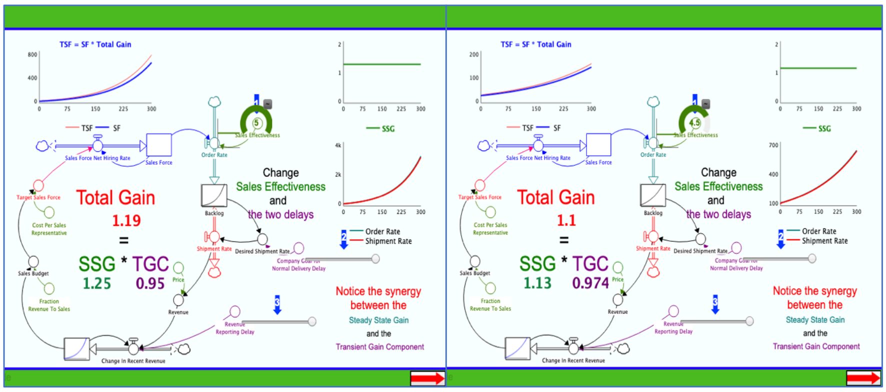


Fig 4.1:- SSGC and TGC giving the Total Gain with Sales Effectiveness 5 and 4.5

The fact is that if there is the delay in the system then the Total Gain would have been almost equal to OLSSG. Let´s now find out how do we express the fact that there is something else that comes in and that is the (Transient Gain Component) TGC.

TGC consists of two things

1. The relationship between Shipment Rate and Order Rate which shows us that how much we ship to manage the orders. It shows us the delay in the process that Shipment Rate is reacting to the Order Rate and that comes from the Company Goal for Normal Delivery Delay.

2. The adjustment the Recent Revenue does with the Revenue , how late is Recent Revenue is compared to actual Revenue.

So,

Transient Gain Component (TGC)

=

(Shipment Rate / Order Rate) *(Recent Revenue/Revenue)

We put Sales Effectiveness to be 4.5 to see the growth. OLSSG is and TGC is 0.97. If we reduce it now it should go toward 1. If we choose between OLSSG and TGC get reduced, that means we are eliminating the transient gain component impact.

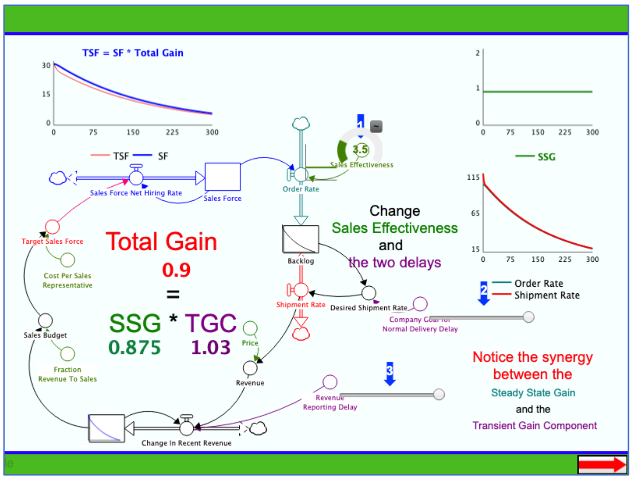
As we know

Total Gain of the system= TGC*OLSSG

Since TGC is being towards one, the Total Gain becomes towards OLSSG. If we put the value of Sales Effectiveness below 4 i.e. we go towards the decay. By this TGC becomes +ve at first because it holds the movement back. We can see that by going back and forth towards growth and decay simultaneously by making Sales Effectiveness more than 4.

In the case of growth e.g. when it is +ve OLSSG is 1.13 TG is 1.1. the reason is that the TGC is less then 1, so, the TGC holds back the growth. The total gain is the growth of the system, the actual growth and the SSG is what we would like to have as our growth. If we multiply the TGC with SSG resulting from the delay, then the total gain becomes less i.e. the growth is less. When we reduce the delay, we can see the total gain is approaching the SSG. So, in another words SSG sets the goal for the growth and TGC holds the system back from that growth and net result is something that initially not as much as indicated by the SSG but less. As we reduce the delay, TGC goes toward the 1 and multiply the SSG with 1 and we get the Total Gain. When we have more delay Target Sales Force grows and Sales Force should grow accordingly. But it does not grow as much as Target Sales Force because TGC holds back the growth with major delay. The reason is that we have delay which are indicated by the TGC namely the relationships between the Shipment Rate and Order Rate and the relationship between Recent Revenue and Revenue, each caused by a delay in their relative adjustments. So, when the delay in adjustment is large the calculated TGC is less than 1 and holds back the growth. Therefore, the total growth which determines how much you actually grow is lower than the SSGC which is determined by all the parameters.

Similarly, in the case of decay, TGC holds back the decay. Here, the SSGC is less than 1 that's why there is decay 0.875 (Fig 5.2), but the gain we have larger than that. The reason to hold back the decay is the multiplication of SSG with a number which is larger than 1. Because it is a bit lower than 1, there is not so much decay. This indicates that when there is decay, the Shipment Rate is larger than the Order Rate because the Order Rate is coming down and with delay the Backlog is coming down accordingly and therefore the Shipment Rate is coming down afterwards. Similarly, Revenue is falling, and Recent Revenue falls slower than the Revenue. As we reduce the delay, TGC goes towards one which when multiplied with SSG gives the Total Gain which is almost equal to SSG.



<u>Fig 4.2:- Exponential decay by Sales Effectiveness less than 4</u>

Now, if we increase the delay, we can see the Sales Force should grow as much as Target Sales Force. So, we can see the growth is considerably less than what it should be, and the reason is delay in the system. Similarly, Revenue is falling but Recent Revenue falls slower with the delay. The longer that delay, larger is the TGC and is the indication of the Shipment Rate is larger than the Order Rate. Therefore, this number which is multiplication of these is going to be larger than 1. Here SSG component which is less than 1 is multiplied with a number that is larger than 1 resulting 0.9.

It shows when the system is having growth, the delay is holding it back and when the system is having decay, the delay is holding it back, developing the resistant to the movement in the system.

Now we try to see the changes by the change in the Goal for Normal Delivery Delay and the Revenue Reporting Delay. If we reduce both the delays to their minimum point, we can see that the TGC becomes almost 1 which means that the total gain is now almost equal to the SSG and thus it has very less effect of holding back the decay and similarly the growth as well if we try for that. What it shows that there are two things that happens in a loop.

1. First whether the big loop is positive or negative feedback loop does not depend on whether the gain is more or less than 1. In one case it is growth which is the big loop is the +ve feedback loop.
2. In other case, if there is decay that is when the SSG is less than 1 and therefore the loop is actually a -ve feedback loop.

So, we get a way of describing the strength of a loop which is much better than to say positive or negative. The same thing with TGC, this is the one which is governed by the negative feedback loop here and they describe holding back the movement that governed by the large loops. Larger the delays, stronger they hold back. The gain gives much more information about the loop than just positive or negative loop characterization does and what the polarity does.

In addition, any loop which is the combination of positive and negative or even negative and more negative that create the behaviour, can be characterized in terms of the SSG and in terms of the TGC which shows what influence do the parameters and delays have on the system. We see that when we are manipulating the delays the SSG is not changed. It gets only changed if any of parameters get changed. If we are not changing any parameters, but only the delays, it always has an impact on the TGC. It means if the signal goes form the Sales Force to the Target Sales Force immediately with no delay than we have a system that develops governed by the SSGC because the TGC is 1 and it does not have any impact.

4.2 Synergy- Sales Force affecting the Sales Effectiveness

After introducing the limited market, change in Sales Force in one hand creates the change directly in Order Rate but also at the same time indirectly it affects the Sales Effectiveness and then the Order Rate by the loop B4. To synergize these two effects, we get more Sales Force we get higher or but at the same time we get the lower Sales Effectiveness and hence the lower Order Rate. In other words, either they strengthen each other or weaken. There is a conflict between the two consequences of increasing the Sales Force. The question here is which one has more effect, whether the change in Sales Force has stronger effect on Sales Effectiveness and then Order Rate or directly on Order Rate? When we simulate the model and increase the Sales Force, at the beginning it has direct impact on Order Rate and it increases but if we further increase the Sales Force it affects Sales Effectiveness, it goes down and the Order Rate goes down eventually. That means if we increase the Sales Force beyond a certain point they become less and less effective. It reflects that there is a point of optimization where the Sales Force works at its maximum and possibly, we can calculate the optimal value for other variables as well. So, there is the possibility for synergy but there is also possibility for the conflict between these two and they multiply with each other and therefor form the strong non-linear relationship.

We can see the dynamics of those two OLSSG and TGC by running the model in both equilibrium condition and before the system reaches to that. At the beginning when we increase the Sales Force, we can see there is a certain growth in Sales Effectiveness but there is still that increase openly in the Order Rate and therefore in the Shipment Rate. As the Sales Force is growing to a very high number, the Sales Effectiveness is dropping down to 4, that means we are approaching a SSG which is 1. It is much more than one in simulation, then we grow less and less and less until it approaches the equilibrium condition. That means the Order Rate, Shipment Rate and Revenue, Target Sales Force, and Sales Force stabilizes one after another. We get a development in the Sales Force which causes the changes in Sales Effectiveness and approach the SSG to drop to 1. These two are creating a dynamics which is closer and closer to an equilibrium. Again, if we now change the Company Goal for Delivery Delay to bring the change in delay in the system, we can see it finally brings the change only in TGC.

4.3 Limited Capacity and Transient Gain

There is also the capacity loop we are building in stages and we get a situation where we can integrate the behaviour into the previously developed model. What we see here is that the Target Sales Force vs. Sales Force, Sales Effectiveness, Order Rate vs. Shipment Rate, Capacity vs. Desired Capacity and the Total Gain graph.

After introducing the capacity loop to the system, at first Sales Force grows significantly following the Target Sales Force but it does not do that for a very long period of time. There is a certain decline in Sales Effectiveness and the Order Rate and Shipment Rate are able to follow each other. The Order Rate initially increased with the growth in Sales Force and Shipment Rate follows that very well because at this point the shipment capacity and the desired capacity are the same. In other words, we do not have any capacity constraint in the beginning.

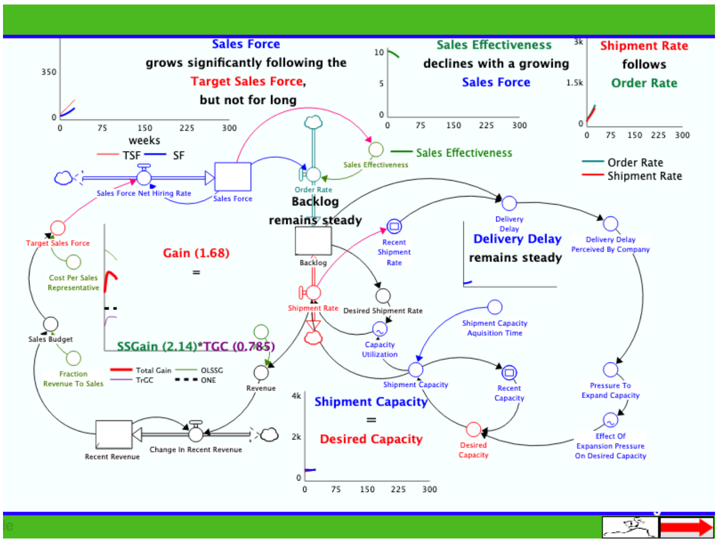


Fig 4.3:- Managing Capactiy at initial Phase

Further simulation shows the Sales Force grows less than it did initially but for much longer period of time and it tries to follow the Target Sales Force. At this point of time the Sales Effectiveness declines significantly with the growing Sales Force. It shows, on the one hand the Order Rate is not growing so much as it did originally but more importantly the Shipment Rate remains below the Order Rate for longer time and the reason is the Desired Capacity to ship hasn't built enough yet to that need. That makes the gap between the Order Rate and Shipment Rate.

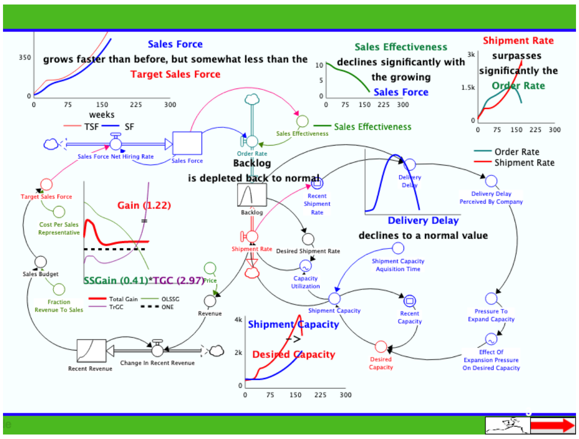


Fig 4.4:- Managing Capactiy

Over the period of time, the TGC has been very low. It held back the growth because the SR has not been able to follow the Order Rate. So, there is a major real delay that exactly creates the pressure for building capacity. Now therefore the growth has been less significant than it used to be. There is still growth but not as large as it used to be.

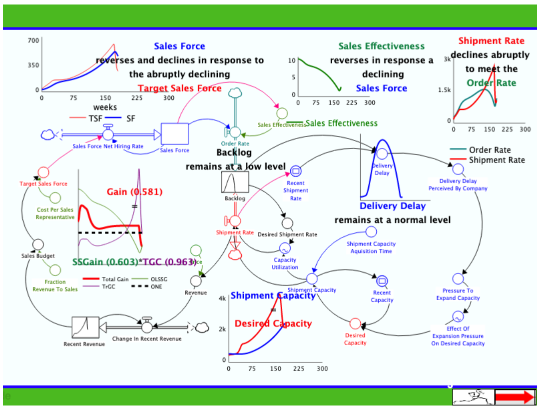


Fig 4.4:- Managing Capactiy at middle phase

With further simulation, there is still growth in the Sales Force and now the Sales Effectiveness is really low which shows the Order Rate is going down now. Meanwhile the Backlog is increased significantly. Now the Backlog is suddenly being empty because there are a lot of Shipments because now the Shipment Capacity has grown significantly and it almost meeting the Desired Capacity. It was growing a lot and comes down after a while in response to very low Order Rate. As the Order Rate is very low and the Shipment Rate is high, then the ratio of these two is much more than 1 and the TGC at this point is increased exponentially almost 3 (2.97) whereas the SSG is very little (0.4). That results a lot of growth in Revenue which further allows the system to grow more and more.

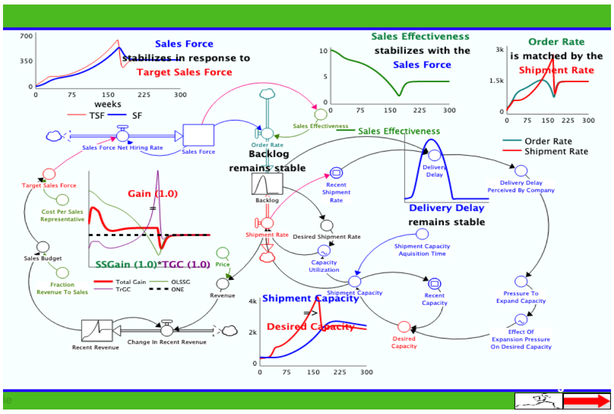


Fig 4.6:- Managing Capactiy throughout the entire time phase

With further simulation the backlog has stabilized, because the Shipment Rate is decreasing towards the Order Rate which results the empty Backlog. At this point the Desired Shipment Rate and the Shipment Rate are balanced, Target Sales Force is very high and there is a lot of income. after a bit further because of lack of Backlog we there is sudden decline in income, Target Sales Force now drops down and Sales Force drops accordingly.

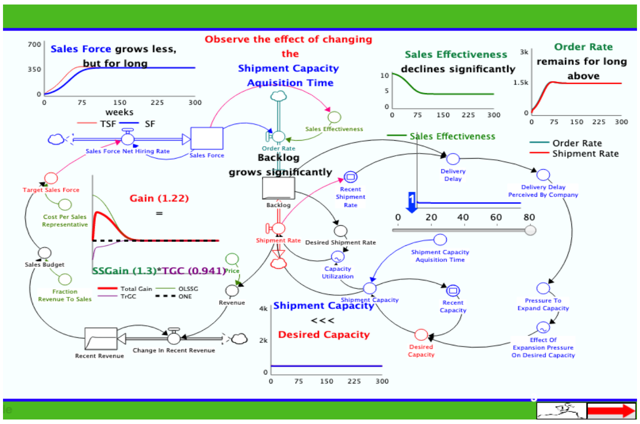


Fig 4.7:- Managing Capactiy with less delay

If we change the delay with which we order so as to build the Capacity, all the oscillations go away. As we increase delay the system gets more and more oscillations. The more delay more the TGC and no delay no any TGC. In other words, we can modify the TGC by altering the delay in the system. That means the system immediately reacts to the delays, there is much disturbance with delays and with no delay system gets into equilibrium faster. That is natural because in capacity loop system immediately reacts to delays while building the capacity needed and starts shipping as per need of the system. This shows that to match the Shipment Rate in accordance to the Order Rate, Capacity Acquisition Time must be reduced.

4.4 Shift the Burden

From above discussions it is clear that the disturbances for creating enough Shipment Capacity are delays. If we say those delays are the burdens for the system to manage Capacity, it can be shifted to the market. By doing that it is market´s responsibility to manage the Order Rate to match with Capacity to Shipment. For that, market looks at the Delivery Delay and manage its Sales Effectiveness so as to reorganize according to the condition.

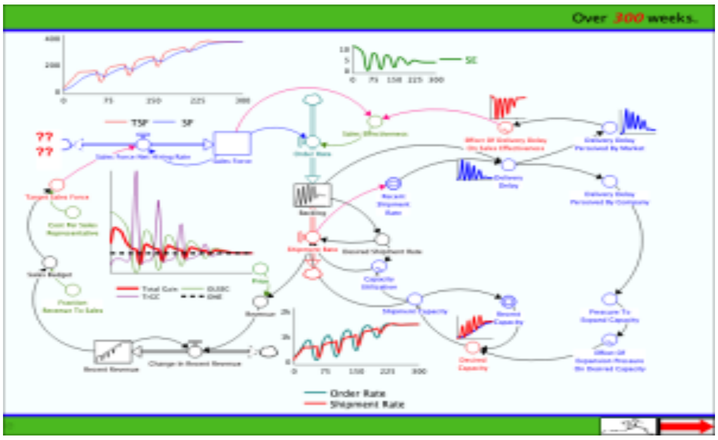


Fig 4.8 :- Market incorporating the delay about the capacity management

When we look at full development over 300 weeks, we see there are many oscillations and each oscillation brings the system in a new level. From time to time the Backlog gets emptied, Sales Effectiveness almost gets to 0 and SSG gets very low accordingly because of the strong impact of the market. Exactly after the Backlog being emptied that means the system has high

Revenue which helps to build capacity again for a period of time and finally the Shipment Capacity is matching the Desired Capacity and the process repeats several times throughout the whole period with each oscillation having less intensity. Each cycle can be observed separately.

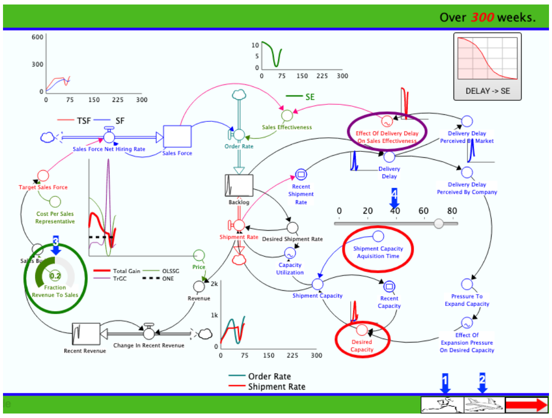


Fig 4.9 :- Market following the delay, the first oscillation

After shifting the burden to the market, if we analyse the first 75 weeks, which is almost the first complete cycle, the simulated behaviour can be described as follows

1 After an initial normal growth in Sales Force, Order Rate, Shipment Capacity and Shipment Rate, the Shipment Capacity does not grow as desired. We are not able to ship as much as we want to and that is an indication of a limitation of our capacity.

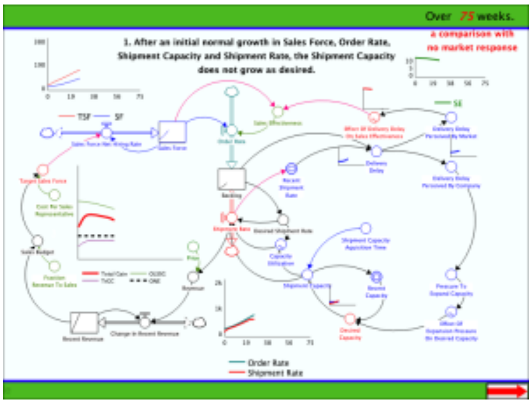


Fig 4.10 :- Market following the delay, the first step

2 Thus a significant Backlog builds up causing the Delivery Delay to grow correspondingly. Though this creates a pressure to expand Shipment Capacity to ensure growth, the Sales Effectiveness declines significantly and faster as a result of a fast market response.

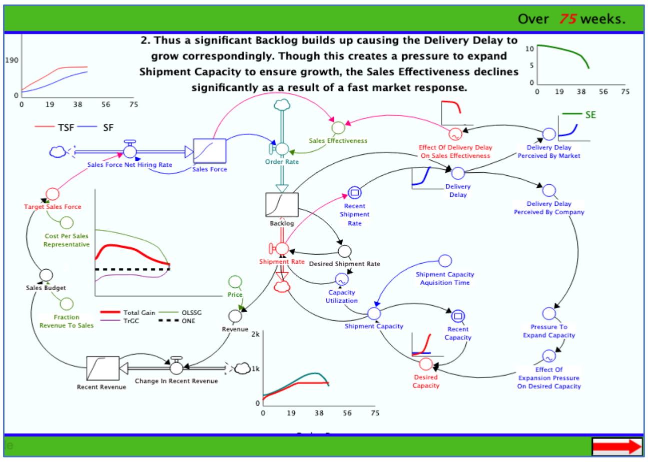


Fig 4.11 :- Market following the delay, the second step

3 This reduces the Order Rate to match and, subsequently, surpass the Shipment Rate that is limited by the Shipment Capacity (i.e. rather than the Shipment Rate matching the Order Rate). Consequently, Revenues remain low and the Sales Force grows very slowly.

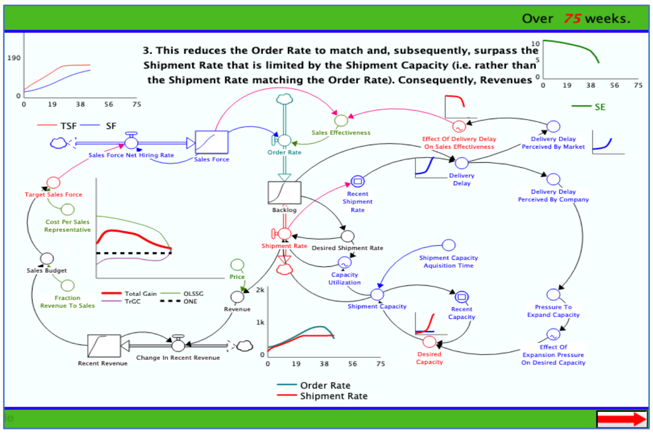


Fig 4.12 :- Market following the delay, the third step

4 The Sales Force dropping, allows for the Sales Effectiveness to rebound (i.e. not remain low) once the Delivery Delay has been normalized.

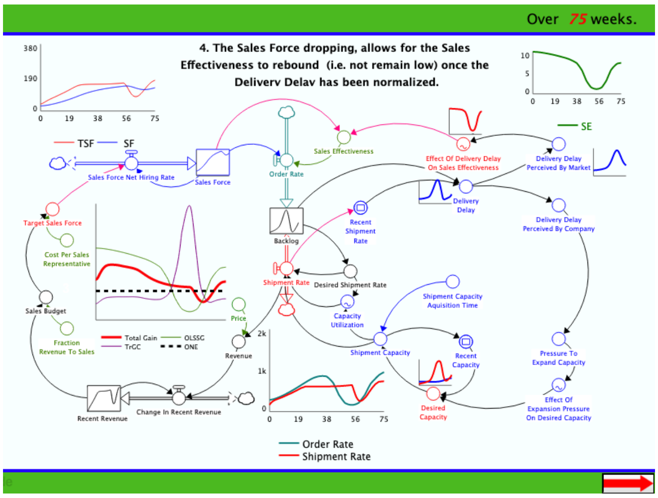


Fig 4.13 :- Market following the delay, the fourth step

5 Thus the Order Rate starts growing, and, in the meantime, the Shipment Capacity has increased so as to allow for the Shipping Rate to follow the Order rate more tightly. This allows for a modest growth in the Sales Force.

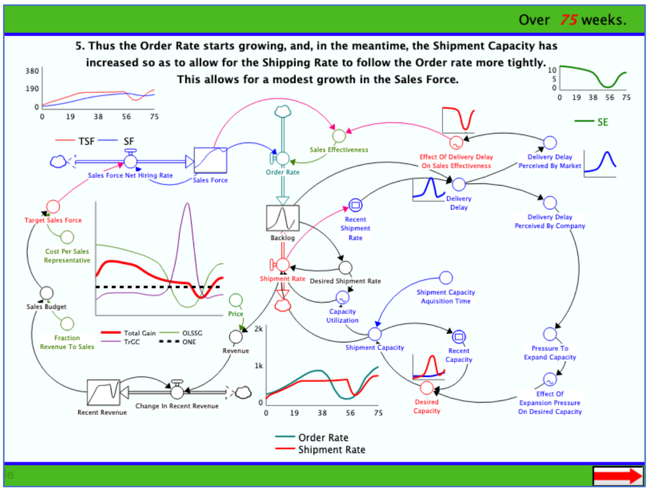


Fig 4.14 :- Market following the delay, the fourth step

6 But, once more, the Shipment Capacity is about to constrain shipping so as to cause the Backlog to grow, the Delivery delay to increase and the cycle to repeat itself

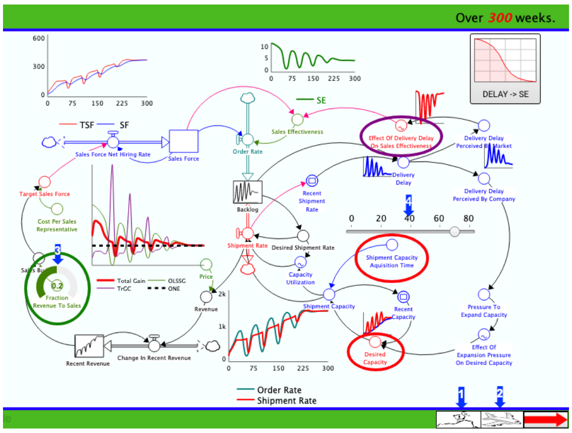


Fig 4.15 :- An overall Market Growth Model reflecting the Reference Mode

4.5 Conclusion

This chapter is particularly focused on the growth concept. The Steady State Growth which was mainly considered as the main growth concept for the model and calculated as the total gain given by the parameters in the system. There are three conditions mentioned about the growth traditionally calculated with respect to OLSSG. If OLSSG is 1 the system is in Steady state condition, if it is more than 1 then the system is having overall growth and if it is less than 1, the system is having overall decay. There was a bit discussion about the transition phase how the system behaves while going from growth and decay condition to the steady state condition. Eigenvalue calculation is one of them. All the discussion about the transition phase are so complicated and not easy to understand.

This chapter is based on the transient phase and believed that there is a Transient Gain Component which plays the role along with the OLSSG while defining the total gain obtained by the system. When the system is in equilibrium condition there is no transient phase and hence not any TGC. But in the case of growth and decay, the system gets into transition and the factor responsible can be calculated by the delays in every stock creating the dynamics. That factor is given the name TGC and is the sum of all the ratios of inflows and outflows for each stock in the system as calculated above.

CHAPTER FIVE: DISCUSSIONS AND CONCLUSIONS

5.1 Introduction

This chapter summaries the topics of this study, draw some conclusions about Interactive Learning Environment (ILE) governed by the purpose of this study i.e. 'flip the classroom from teacher-oriented to learner-driven'. Discussion and conclusions are based on the development of Interactive Learning Environment by using scaffolding of the market growth model. Finally, recommendations for further study would be presented.

This study mainly revolves around the understanding of Market Growth Model developed by Forrester. The aim of this thesis is to facilitate understanding of the Model, a mandatory assignment under GEO-SD 303, a master´s course in System Dynamics. Chapter three is a brief introduction of the Market Growth Model.

5.2 Summary and Discussion

This study is conducted for the development of the computer-based ILE, designed to understand the market growth model as a case on the basis of scaffolding and graduated complexity principles. It is assumed that scaffolding of the market growth model provides the learner the methods, the techniques and the tools for the system dynamics modelling. Stella architect has been used as the system dynamics modelling tool. Among the two inseparable parts of the modelling- behavioural part is the main focus of this study.

The term modelling seems just to create the structural part, but the modelling process constitute both parts side by side in each step. Structure gives the behaviour after simulation and on the basis of thus produced behaviour, necessary additions and modifications could be done in the structural part so as to get the desired output. So, both parts are interdependent and inseparable. The study comprises five chapters-, System dynamics learning facilitated by the interactive learning environment, market growth model, Scaffolding the market growth model, Transient gain component and discussions, conclusions and recommendations.

Chapter one describes the system dynamics learning required engaging in modelling and model-based analysis. It can be used to understand the dynamic systems (Davidson at all. 1999). The basic building blocks are used to develop model structure and then produced model behaviour after simulation. Modern technology can be useful tool for better understanding of the system dynamics.

An existing market growth model is taken for scaffolding to understand the model building, simulation as well as the analysis. To facilitate this process through scaffolding, an Interactive Learning Environment (ILE) was developed using Stella Architect. Chapter one clearly describes problems in system dynamics learning, need for interactive learning environment and how scaffolding could be a supportive tool for creating ILE.

Chapter two presents the discussions about the structural and behavioural learning of System Dynamics, difficulties in SD learning and how interactive learning environment supports the System Dynamics learning. There are two ways of learning system dynamics learning with models and learning by models (Milrad, Spector, & Davidsen, 2003). There are various technologies/software's for the development of model structure and to get their simulated behaviour. The same technologies can also be used to develop such interactive learning environments to support the learning in and about complex systems (Spector & Anderson, 2000). Computer scaffolding has been used to develop the interactive learning environment (ILE) to facilitate both aspects of model facilitate learning – learning with model and learning by modelling. Both Structural and behavioural aspects of the modelling have been produced in brief, but the main attention has been given to the behavioural part. Behavioural learning consists of learning about the different modes of behaviours produced by different structures. There are five major behaviours generally experienced while simulating the system dynamics model as; exponential growth/decline, goal-seeking and oscillations, s-shaped growth, s-shaped growth with overshoot and overshoot and collapse.

Discussions continue to explain dynamics complexities associated with complex dynamic modelling learning. According to Sterman there are various complexities (factors) which hinder the learning about complex systems and such complications arise due to the difficulties in understanding accumulations, feedbacks, delays, and non-linearities. Those are taken as the main causes for making learning complex dynamic systems difficult(challenges) for the study purpose (Sterman, 2000).

To make complex system learning easy, two co-existing principles- scaffolding and graduated complexity- are taken as basis for developing Interactive Learning Environment (ILE). In graduated complexities focus has been made to create layers of gradually increasing complexity that people can navigate from simple to complex. Scaffolding aims at promoting not only the capacity but also the willingness to perform complex tasks independently (Belland, Kim, et al., 2013). This study focused on developing student-cantered scaffolding in which learner gets support by facilitators providing the scaffolding support to new students in need (Davin & Donato, 2013; Pata, Lehtinen, &Sarapuu, 2006; Sabet, Tahriri, &Pasand, 2013 cited in Belland, 2017).

Chapter three attempts to reconstruct the necessary structures of different sectors of the market growth model and resulting behaviour in brief. Attention has been paid on how to build the structure step by step. It explains each sector of market growth model mainly consists of order fulfilment, revenue generation, sales force management, the market effect, profit, open loop steady state gain, capacity utilization and its impact on market. Order fulfilment sector explains how the Order Rate is determined by the salesperson and their effectiveness. Revenue generation sector describes accumulated revenue is the function of the order fulfilment and revenue reporting delay. The Sales Force subsystem links the Order Rate, Backlog, Shipment Rate, Revenue, Sales Budget and closes the sales growth loop R1 by adjusting the Sales Force with respect to Target Sales Force. The market sector describes the possibility of optimum level of market expansion which creates market potential and determines Optimum Sales Force.

The OLSSG is the multiplier that relates the response of the Target Sales Force (effect) back to a unit change in the Sales Force (cause). A unit change in the Sales Force produces a steady state change in the Target Sales Force which gives the value of OLSSG. It determines whether the firm grows or declines, the rate of growth depends on the time constants of the delays in the loop, the shorter the delay time, the faster the growth rate.

Chapter four is the main part of this work presenting the development of Interactive Learning Environment. Attentions have been focused on communicating the simulated behaviour and the reasons behind such behaviour and design computer-based scaffolding so as to build the Interactive Learning Environment. Further, computer-based scaffolding has been used as the computer-based support that will help students to gain the skills at doing tasks that are beyond their unassisted abilities. The scaffolding is based on different steps on the principle of graduated complexity. Stock and flow diagrams have been developed on the basis of statements given in the mandatory assignment. Scaffolding was designed step by step in STELLA architect. Discussions about the scaffolding of structures with their corresponding equations and the corresponding simulated behaviour of those structures were done.

The scaffolding has been started with the basic parts of the model where Sales Force, Backlog and Revenue were the main stocks accumulated after the corresponding flow rates. The mindset for the basic part there is the unlimited market i.e. there is no constraints for the production capacity. The model was further expanded by adding components of market response, capacity utilization and effect of suck capacity utilization back on the market situation. Introduction of the saturated market situation endogenizes the Sales Effectiveness and optimization of the Sales Force part has been introduced to find the Optimal Profit situation for the company.

Discussions and explanations about the feedback loops and their resulting effects on the system has been done. There are nine balancing and three reinforcing loops in the system. Sales Force mainly dominated by R1 and B4. R1 tends to exponential growth in the Sales Force when it is strong; Market demand (loop B4) tends to control Order Rate by adjusting Sales Effectiveness. R2 explains how the higher Current Capacity reinforces the further expansion of Current Capacity. The reinforcing loop R3 determines the capacity expansion in the system it includes the basic market growth sector incorporating the capacity sector within it and hence replaces the previous major reinforcing loop R1. Balancing loops B1, B2 and B3 are local balancing loops interplaying in the Sales force Growth loop (R1). Balancing loop B5 regulates the Shipment Rate in the short run, ´within´ the existing Shipment Capacity constraints by the way of the Capacity Utilization. There are two local balancing loops B6 and B7 affecting capacity expansion simultaneously with the reinforcing loop R2. The two major balancing loops B8 and B9 appear simultaneously after the capacity utilization sector in the model. The balancing loop B9 complements the balancing loop B8 and regulates Backlog and Shipment Rate in the system. The triplet of the negative loops B8, B9 and B5 serves the purpose of aligning the Shipment Rate with the Order Rate in the context of limited Capacity of the market.

Structure governing the Capacity Expansion (B8 and B9) and Market Response to Delay loop (BX) explains the dynamics of Capacity Development and Market Response to Delivery Delay. Interplay between two loops generates oscillating behaviour in Order Rate and Shipment Rate. Capacity Expansion governs the Shipment Rate and Market Response to Delay governs the Order Rate.

5.3 *Conclusion and Recommendations*

The purpose of this study is to design scaffolding for the development of Interactive Learning Environment. the whole study focused on how to enhance the learning of system dynamics by shifting teacher centred to student centred learning approach. Learning is the process whereby knowledge is constructed by the transformation of experience (Adobor & Daneshfar, 2006; Kolb, 1984; Wall & Ahmed, 2008). According to Sterman, J.D. (2000) Learning is a feedback process for making our decisions to alter the existing situation. Feedback is the behaviour which affects the output. Structural description, behavioural description and graphical integration enhances the understanding of the most generic process that links structure to behaviour in dynamic systems (Pål I. Devidsen, 1991). System dynamics have characterized such tasks by feedback processes, time delays, and non-linearities in the relationships between decision task variables (Moxnes, 2004; Sterman, 1989a).

This research has used the STELLA architect for developing ILE. Sufficient attentions have been paid to scaffold the Market Growth Model as a case considering Structural description and behavioural description. The principle of gradual complexity was basic guiding principle to this study. Overall market growth model covers the production and the market sector. There are Sales Force growth, Order Fulfilment, Production Capacity and Customer Demand. In the basic part structure relating to Sales Force and Order Fulfilment, the assumptions were there were no any restrictions for production capacity to fulfil the customer demand. Sales Effectiveness determined the Order Rate and Shipment Capacity with certain delay. Parameter values such as Price, Cost, Fraction Revenue to Sales, and Reference Sales Effectiveness and Delay components with level variables have remarkable effect on the behaviour produced after the simulation.

In task three we added capacity component in the model and the system behaviour with different values of various parameters. We examined Capacity Expansion Cost and its effect on Revenue available for Sales Budget. In such situation we found the Optimal Steady State of the system has been changed.

In task 4 we added structure that consider Market Response to Delay. To this additional structure, there is balancing loop BX which works on Delivery Delay and Market Response to that Delay. This also adjusts Order Rate by adjusting Sales Effectiveness. The model developed in task four explains the behaviour of the four companies portrayed in figure 1 in the problem statement. This stage of market growth model explains why greater Sales Force reduces the Sales Effectiveness, controls Order Rate by adjusting Sales Effectiveness and manages Shipment Rate by adjusting Capacity.

At last, attempts have been paid to characterize the overall model behaviour in terms of the behaviour mode arising from Sales Force adjustment in the medium term, Capacity Expansion in the long run and Market Response to the Delivery Delay by influencing the Sales Effectiveness. Finally, we explain the interplay between the loop governing the Capacity Development and the loop governing the Market Response to Delivery Delay

ILE has been developed for the students of GEO-SD 303 course to replace the classroom teaching for that particular assignment. Assumption before building this ILE was the students have already gone through the ILE developed for the understanding of the structural part of the modelling. In conclusion, it is assumed that this study has been useful for new student to understand market growth model so as to understand the behavioural part of the modelling. Complexities arise gradually with the addition market saturation and capacity utilization part.

Even though remarkable efforts have been spent on developing this research work, however, there are still some limitations associated with it. Further enhancement will be easy based on this study. There are some findings that could be taken consideration for further study.

- Overall system produces three different reinforcing loops (R1, R2 and R3) one at each sector of the market. Each feedback loop has certain delay and all the delays have more or less effect on the overall growth of the system. In such circumstances, we need to calculate the transient gain through each feedback loop. The term transient gain component is given by Proff. Pål I. Davidson for the gain each feedback loop gets just before it goes to the steady state condition. According to him the total gain of the whole system is equals to the summation of all the individual gain accompanied by each feedback loop of the system. It will give the new dimension to the study of the modelling process and helps to justify the growth before the model gets into its equilibrium situation.
- The ILE developed in this study can be used in new classes of System Dynamics for learning and teaching Market Growth Model. The further improvement in Scaffolding will be possible on the basis of feedbacks from participants (students).
- This study will be better reference study for understanding market growth model and System dynamics modelling as a whole particularly for understanding of the behaviour produced after simulation.

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